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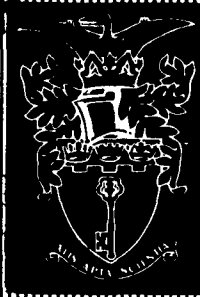
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FATIGUE CRACKING RATES AND RESIDUAL STRENGTHS OF EIGHT ALUMINIUM SHEET ALLOYS

by

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MINISTRY OF AVIATION
FARNBOROUGH HANTS

R O Y A L   A I R C R A F T   E S T A B L I S H M E N T

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SUMMARY

Eight aluminium sheet alloys were tested as $6\frac{1}{2}$" wide 16 SWG panels
containing $\frac{1}{2}$" central transverse slots, to compare the propagation rates of
fatigue cracks which grew from the slots under $P \pm p$ type stressing. The
results are given as cracking rate vs crack length curves. With the lowest
stress cycle, 14,000 ± 2000 psi, cracking rates at 1" crack lengths ranged
from 0.16×10^{-5} in/cycle in Hiduminium 54 to 1.1×10^{-5} in/cycle in DTD.687A,
the rate in DTD.5070 sheet being 0.36×10^{-5} in/cycle. With the highest
stress cycle, 18,000 ± 4000 psi, cracking rates at 1" crack lengths were about
10 to 20 times faster, and again the DTD.5070 sheet had an intermediate rate
similar to those of DTD.546B and 2024-T81. Heating 2024-T81 and DTD.5070
panels for 1000 hours at 150°C caused only small changes in cracking rates,
and rates measured in tests at 150°C were very similar to those at room
temperature. Residual strengths at 1" crack lengths ranged from 37% for
X 2020 to 67% for DTD.546B and Hiduminium 54, with DTD.5070 retaining 64%.

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1 INTRODUCTION

The work described in this Note was carried out mainly in connection with the M 2.2 supersonic transport project. During the feasibility study and design study stages of the project several different alloys were considered and compared to assess their relative merits for use as the principal structural material, or for making some major component. Many different mechanical properties had to be considered in making these assessments, and at the outset little or no data existed on some of them, so several programmes of tests were formulated, and shared between a number of laboratories. At first these co-operative test programmes did not include fatigue crack propagation rate measurements and residual strength tests on cracked panels, so some small scale equipment, which was being developed at R.A.E., was used to obtain preliminary data comparing the candidate alloys in respect of these properties.

The panels used for both types of measurement were 10" long and $6\frac{1}{2}$" wide, and contained a $\frac{1}{2}$" long transverse central slot. These panels were subjected to tensile fatigue stresses of the $P \pm p$ type at a frequency of 2600 cycles/minute, and the rate at which the fatigue cracks progressed across the panel from the slot was measured. Alternatively, the cracks were grown to chosen lengths before transferring the panel to a tensile testing machine to determine its residual strength.

Altogether eight alloys were tested at room temperature in the as-manufactured condition, the DTD.687A Al-Zn-Mg-Cu-Mn alloy being included to complete the range of standard alloys available for comparison. All were in the form of 16 S.G sheet, and except for the SAP sheet all were clad with pure aluminium or an Al-1-Zn alloy. Two of the candidate alloys, 2024-T81 and DTD.5070, were also tested at 150°C and at room temperature, after heating for 1000 hours at 150°C. Some additional tests were made on the DTD.546B and DTD.5070 alloys using $4\frac{1}{2}$" wide panels, to estimate the dependence of cracking rate on panel width; and the dependence of cracking rate on mean stress (P) and alternating stress (p) was studied by tests on the DTD.546B alloy.

2 MATERIALS TESTED

Single 6' × 3' sheets provided enough material for the tests on six of the alloys, except that four sheets of DTD.546B were used, and three sheets of DTD.5070. In these cases where more than one sheet was used they were taken from the same cast and heat-treatment batch. Table 1 gives the analysed core

compositions of the eight materials, and the heat-treatments specified for them.

3   TESTING EQUIPMENT AND PROCEDURES

3.1   Tensile test-pieces

The lower drawing in Fig.1 shows the standard $8" \times 1\frac{1}{2}"$ test-piece used for determining the ordinary longitudinal tensile properties of the sheets, which are recorded in Table 2. On one of the DTD.546B sheets (No.5) two further tensile tests were made using larger longitudinal test-pieces. These measured $10" \times 6\frac{1}{2}"$ but were reduced over the central $3"$ to form a parallel portion $5"$ wide. They were made and tested to ascertain whether any size effect existed with respect to tensile strength. Their measured tensile strengths were 28.8 and 28.6 tsi, and as reported in Table 2 the duplicate standard test-pieces from the same sheet had strengths of 28.8 and 28.7 tsi. Thus the size effect appeared to be negligible, and later, when the residual strengths of cracked panels were being expressed as a percentage of the original strengths, the latter were assumed to be the same as those of the small standard test-pieces.

3.2   Crack propagation test-pieces

Details of the $6\frac{1}{2}"$ wide panels used for most of the crack propagation rate and residual strength measurements are also shown in Fig.1. They were cut from the sheets with their long sides parallel to the direction of rolling. The two $\frac{1}{8}"$ diameter holes were drilled to allow a $0.007"$ thick saw blade to be inserted for cutting the slot. The ends of the slot were burnished to an approximately semicircular shape, as shown in Fig.2. Jigs were used for the drilling and slotting operations. When the steel friction grips were attached to the panel its free length was reduced to $8.9"$ giving a free length/width ratio (L/W) of 1.37. The $4\frac{1}{2}"$ wide panels used to study the effect of panel width on cracking rate were identical to the larger panels in their other dimensions.

The scale shown on the panel in Fig.1 was applied by a photoprinter's technique. The panel was cleaned and degreased and was then coated with a light-sensitive emulsion and whirled to obtain a uniform thickness. When the emulsion was dry a glass negative of the scale was placed over the panel in a vacuum printing frame, which was then exposed to a carbon arc lamp for about twenty minutes. The unexposed emulsion was then washed away with tap water and the exposed emulsion was dyed with a printer's black ink.

3.3 Testing machine and load measuring technique for crack propagation tests

The crack propagation rate measurements were made in the 6 ton Schenck Pulsator shown in Fig.3. Mean and alternating loads were measured by resistance strain gauges cemented to the ring dynamometer of the machine, the gauges forming part of a Wheatstone bridge circuit[1]. The amplitude of the alternating load was maintained to within ±5% of the desired value by an electronic controller. The frequency of the alternating load was approximately 2600 cpm.

3.4 Measurement of crack lengths

A Shackman 35 mm Auto-Camera Mark III, mounted over the test panel, was used to record the progress of the fatigue cracks from the central slot, and the elapsed number of stress cycles, as indicated by an electrically operated counter. A photograph was taken automatically at half hourly intervals during the early stages of the test, that is up to a total length of slot and cracks of about 3" in a $6\frac{1}{2}$" panel. This was arranged by two microswitches mating with a two lobe cam mounted on a motor driven shaft rotating at one revolution/hour. One switch completed the illumination circuit and the other one operated the camera. Subsequently, when the cracks were growing at a fairly fast rate photographs were taken by manual switching; but in the final stages of the test automatic switching was used again to obtain a photograph at every tenth stress cycle. This rate was given by a third microswitch mating with a cam driven by reduction gearing from the Pulsator motor. The Kodak Plus X film was developed in Microdol to give a fine-grain record from which it was possible to measure the "crack length" ℓ(total length of slot and two end cracks) to within 0.025", by using a X 10.5 binocular viewer. From these measurements and the counter records a graph of crack length versus number of stress cycles could be plotted. As examples the results of duplicate tests on Hiduminium 72 panels are shown in Figs. 4 and 5. Rates of crack propagation ($d\ell/dN$) were derived from these curves by drawing tangents to them at selected time intervals. Fig.6 shows the crack propagation rates plotted against crack lengths for the two tests on the Hiduminium 72 panels. This type of rate curve formed the basis of many of the comparisons recorded in this report.

3.5 Crack propagation testing at 150°C

For the tests at 150°C a small heating pad was strapped to the panel. This consisted of two flat Syndanio plates between which the test panel was sandwiched; the lower plate carried a flat heating element, and the upper plate

had a central slot through which the scale on the panel could be photo-
graphed. The test temperature was controlled by a Sunvic energy regulator
and was recorded on a Kent recorder. Temperature gradients were measured at
the outset using several thermocouples which had been spot welded to a panel
on both sides of the crack line and $\frac{1}{2}$" away from it. The measured deviations
from the intended temperature were within $\pm 3^\circ C$. In subsequent tests only one
thermocouple was attached to the panel, this being on the longitudinal
axis and not more than $\frac{1}{4}$" from the slot. The panel was heated to test
temperature in thirty minutes and then soaked for one hour before starting
the test.

4 COMPARISON OF MATERIALS

4.1 Crack propagation rates in as-received materials

Crack propagation rate measurements were made on the eight materials at
two or more of the following stress cycles:-

$$14000 \pm 2000 \text{ psi}$$
$$14000 \pm 4000 \text{ psi}$$
$$18000 \pm 2000 \text{ psi}$$
$$18000 \pm 4000 \text{ psi}$$

Four of the materials, DTD.546B, Hiduminium 72, 2024-T81 and DTD.5070,
were tested with all four stress cycles. The fatigue stresses quoted here and
in subsequent sections were calculated on the initial cross-sectional area
at the slot line, i.e. on (width - $\frac{1}{2}$") $\times$ thickness in^2. In almost all cases
duplicate panels were tested.

The 14000 and 18000 psi mean stresses were selected for the tests as
being typical 1g aircraft stress levels, and the alternating stresses allowed
the tests to be completed in a working day, so that the operator could always
be present during the later stages of the test. Room temperature endurances
ranged from about 5×10^4 to 7.5×10^5 cycles.

The results are given in full in Tables 3 - 6, and the average results
of the duplicate tests are plotted as crack propagation rate vs crack length
curves in Figs. 7-10. As cracking rates at small crack lengths are of most
practical importance, a simple comparison of the materials can be made, as in
Table 9, by considering only the cracking rates when the cracks are 1" long.
With the lowest stress cycle of 14000 $\pm$ 2000 psi the cracking rates at 1" crack
lengths ranged from 0.16×10^{-5} in/cycle for Hiduminium 54, to 1.1×10^{-5} in/
cycle for DTD.687A, and the favoured candidate alloy DTD.5070 had a slightly

slower rate than the widely used DTD.546B alloy. At the highest stress cycle, 18000 ± 4000 psi the cracking rates at 1" crack lengths were 7 to 23 times faster, ranging from 1.1×10^{-5} in/cycle for Hiduminium 54 to 10.5×10^{-5} in/cycle for X 2020, and again the DTD.5070 alloy had an intermediate rate similar to those of the DTD.546B and 2024-T81 alloys.

4.2 Crack propagation rates in 2024-T81 and DTD.5070 panels after heating for 1000 hours at 150°C

Duplicate panels cut from the 2024-T81 and DTD.5070 sheets were tested with stress cycles of 14000 ± 2000 psi and 14000 ± 4000 psi, at room temperature and at 150°C, after heating for 1000 hours at 150°C; other work had shown that heating for 1000 hours at 150°C caused approximately the same reduction in 0.2% proof stress as 30,000 hours at 120°C. The results of the room temperature tests are given in Table 7, and those of the 150°C tests in Table 8.

In Fig.11 the average results of the duplicate tests on the 2024-T81 panels are plotted as crack propagation rate vs crack length curves, and the corresponding curves for the as-received sheet are repeated to show the effect of the 1000 hours heating at 150°C on the room temperature crack propagation rates. Fig.12 gives the corresponding results for the DTD.5070 sheet.

Average crack propagation rates in the two materials, at 1" crack lengths, after heating for 1000 hours at 150°C, are included in Table 9, from which it will be seen that the heating had only small effects on crack propagation rates, and that crack propagation rates at 150°C were very similar to those at room temperature.

4.3 Residual strengths of cracked panels

Several panels in each of the eight materials were fatigue stressed in the Schenck Pulsator to produce cracks of different lengths, and were then transferred to a tensile test machine to determine their residual strengths, which are recorded in Table 10. The crack lengths shown in this table were measured with a rule before the panels were taken out of the fatigue machine, and were checked after the panels had been broken in the tensile machine, the ends of the fatigue cracks being clearly visible on the fracture surfaces. The residual strengths quoted in Table 10 were calculated on the gross cross-sectional area of the panels, i.e. on the full panel width multiplied by the panel thickness. In Figs.13 and 14 the results are shown in a non-dimensional form, the residual strength of each panel, expressed as a fraction of the original uncracked tensile strength of the material, being plotted against the

crack length, expressed as a fraction of the panel width. And in Fig.15 the results for the DTD.546B panels are plotted again together with data derived from the end points of panels used for crack propagation rate measurements. For these panels the residual strength was taken as the peak stress of the fatigue cycle, calculated now on the gross cross-sectional area of the panel, and the crack length plotted is that at which final instantaneous failure occurred in the fatigue machine. Plotted in this way the results for the crack propagation rate panels lie reasonably close to the line through the points for the panels broken in the tensile machine. The data from the crack propagation rate panels is also given in Table 11.

Table 12 compares the eight materials in terms of the residual strengths of $6\frac{1}{2}$" wide panels all containing 1" long central cracks, derived by interpolation from Figs.13 and 14. These residual strengths in the presence of 1" cracks ranged from 37% (for X 2020) to 67% (for DTD.546B and Hiduminium 54) of the original uncracked strengths.

5   EXPLORATORY STUDY OF THE EFFECTS OF THREE TESTING VARIABLES ON CRACK PROPAGATION RATES

5.1   Effect of panel width

To obtain preliminary information on this effect the crack propagation rate measurements made with stress cycles of 14000 ± 2000 psi and 14000 ± 4000 psi on DTD.546B and DTD.5070 sheets, using $6\frac{1}{2}$" wide panels, were repeated on $4\frac{1}{2}$" wide panels which were otherwise identical to that shown in Fig.1. The results are given in full in Table 13 and the average results of the duplicate tests are compared with those for the wider panels in Figs.16 and 17. For crack lengths up to 2" for both materials the cracking rates at 14000 ± 4000 psi in the $4\frac{1}{2}$" panels were very similar to those in the $6\frac{1}{2}$" panels, but at 14000 ± 2000 psi the rates in the $4\frac{1}{2}$" panels were lower than in the $6\frac{1}{2}$" panels. Further work has been carried out on this effect and is being reported separately[2].

5.2   Effect of mean stress

Table 14 gives the results of some additional tests, carried out on $6\frac{1}{4}$" wide DTD.546B panels to investigate this effect over a wider range of mean stresses than had already been employed. The average results of duplicate tests with stress cycles ranging from 6000 ± 2000 psi to 18000 ± 2000 psi are compared in Fig.18. For crack lengths up to 2" cracking rates were relatively insensitive to changes in mean stress within the range investigated.

5.3 Effect of alternating stress

To study this effect over a wider range of stresses, additional tests were carried out on $6\frac{1}{2}$" wide DTD.546B panels, with stress cycles of 14000 ± 1000 psi, 14000 ± 3000 psi, and 14000 ± 6000 psi. The results are given in Table 15, and are compared with those obtained previously at 14000 ± 2000 psi and 14000 ± 4000 psi in Fig.19. Cracking rates increased rapidly and progressively with increase of alternating stress; for instance, doubling the stress increased the cracking rate at 1" crack length by a factor of 5 or more.

6 CONCLUSIONS

(1)   In tests with the lowest stress cycle used for comparing crack propagation rates in the different materials, i.e. 14000 ± 2000 psi, cracking rates at 1" crack lengths in $6\frac{1}{2}$" wide panels ranged from 0.16×10^{-5} in/cycle in Hiduminium 54 to 1.1×10^{-5} in/cycle in DTD.687A, and the DTD.5070, RR.58 alloy sheet, had a slightly lower rate than the widely used DTD.546B alloy. In tests with the highest stress cycle, 18000 ± 4000 psi, cracking rates at 1" crack lengths were about 10 to 20 times faster, ranging from 1.1×10^{-5} in/cycle in Hiduminium 54 to 10.5×10^{-5} in/cycle in X 2020, and again the DTD.5070 alloy had an intermediate rate similar to those of the DTD.546B and 2024-T81 alloys.

(2)   Heating 2024-T81 and DTD.5070 panels for 1000 hours at 150°C caused only small changes in fatigue crack propagation rates in these materials, and crack propagation rates measured in tests at 150°C were very similar to those at room temperature.

(3)   Residual strengths of $6\frac{1}{2}$" wide panels containing 1" long central fatigue cracks ranged from 37% (for X 2020) to 67% (for DTD.546B and Hiduminium 54) of the ordinary uncracked tensile strengths, with DTD.5070 retaining 64%.

(4)   In tests with a stress cycle of 14000 ± 4000 psi cracking rates in $4\frac{1}{2}$" wide panels of DTD.546B and DTD.5070 were very similar to those measured previously in $6\frac{1}{2}$" wide panels, but with a lower stress cycle of 14000 ± 2000 psi the rates at crack lengths up to 2" were lower in the $4\frac{1}{2}$" panels than in the $6\frac{1}{2}$" panels. Further work on the effect of panel width is being reported separately.

(5)   In tests on $6\frac{1}{2}$" wide DTD.546B panels, with stress cycles ranging from 14000 ± 1000 psi to 14000 ± 6000 psi and from 6000 ± 2000 psi to 18000 ± 2000 psi, crack propagation rates increased rapidly and progressively with

increase of alternating stress, but were substantially unaffected by changes
in the mean stress.

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TABLE 1 — Core compositions and specified heat-treatments of materials tested

Material	Analysed core composition — wt %											Specified heat-treatment
	Cu	Mg	Si	Fe	Mn	Li	Cd	Ti	Zn	Ni	Al_2O_3	
DTD 546B	4.49	0.49	0.79	0.45	0.78	–	–	–	–	–	–	Solution treatment at 510 ± 5°C, aging in the range 155 – 205°C.
Hiduminium 72	4.47	1.28	0.20	0.29	0.64	–	–	–	–	–	–	Solution treatment at 490 ± 5°C, aging at room temperature.
2024-T81	4.26	1.43	0.15	0.33	0.60	–	–	–	–	–	–	Solution treatment at 488-499°C, aging at 188-193°C.
X 2020	4.57	–	–	0.26	0.53	1.05	0.16	–	–	–	–	Solution treatment at 510-521°C, aging at 160°C.
Hiduminium 54	5.81	0.21	0.16	0.38	0.23	–	–	0.15	–	–	–	Solution treated 15 m at 530°C, cold water quenched and aged 16 hours at 195°C (actual treatment).
DTD.687A	1.20	2.60	0.14	0.34	0.27	–	–	–	5.50	–	–	Solution treatment at 465 ± 5°C, aging in the range 110 – 140°C.
DTD.5070	2.51	1.55	0.23	1.04	0.02	–	–	–	–	1.13	–	Solution treatment at 530 ± 5°C, aging at 200 ± 5°C.
SAP	–	–	–	–	–	–	–	–	–	–	13.5	–

TABLE 2 - Results of tensile tests on the eight sheet materials using standard 8" × 1½" test-pieces

Material	Sheet number	Test-piece number	0.1% PS tsi	0.2% PS tsi	TS tsi	E 10⁶ psi		Elong. on 2" %
DTD 546B	1	1.7	25.4	26.0	28.8	10.2	9.6	9
	2	2.25	25.2	25.6	28.6	10.5	9.8	11
		2.26	25.2	25.6	28.5	10.5	9.8	9
	3	3.5	25.5	26.0	28.9	10.6	9.7	10
		3.10	25.4	25.8	28.6	10.6	9.7	10
	5	5.6	25.4	26.0	28.8	10.3	9.6	10
		5.11	25.5	25.9	28.7	10.1	9.4	10
Hiduminium 72	1	W1L	22.9	23.1	29.7	10.5	9.5	17
		W2L	23.0	23.2	29.7	10.4	9.5	18
2024-T81	1	42.9L	30.2	30.6	32.0	10.4	9.7	7
		42.10L	29.2	29.6	31.3	10.2	9.7	7
X2020	1	01.7	31.4	31.8	33.2	11.1	9.7	7
		01.9	31.0	31.3	32.5	11.1	9.6	6
		01.11	31.2	31.6	32.8	11.0	9.6	7
		01.13	30.6	31.0	32.4	11.0	9.5	7
Hiduminium 54	1	D1.2	19.9	20.5	25.6	10.4	9.7	9
		D8.2	19.9	20.4	25.6	10.3	9.6	10
DTD.687A	6	6.6	33.5	34.2	36.5	10.2	9.3	11
		6.7	33.0	33.8	36.4	10.0	9.2	12
DTD 5070	1	R4	23.0	23.4	26.2	10.9	10.1	7
		R20	23.4	23.8	26.3	11.0	10.1	7
	2	R51	23.1	23.6	26.2	10.6	9.9	7
		R69	23.1	23.5	26.2	10.5	9.8	7
	3	R77	22.8	23.2	25.8	10.6	9.6	7
		R82	23.1	23.4	26.1	10.7	9.9	8
SAP	1	S25L	15.3	18.5	23.7	10.6		6
		S26L	15.7	18.8	23.9	10.4		6

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TABLE 3 - Results of crack propagation tests at 14000 ± 2000 psi

Material	Test No.		Cracking rate (dl/dN) and crack length(l) after N stress cycle							
DTD 546B	27	N - 10⁵ cycles	2.00	3.00	4.00	4.50	5.00	5.15		
		dl/dN - 10⁻⁵ in/cycle	0.19	0.31	0.71	1.0	3.5	8.8		
		l - in	0.75	1.00	1.50	1.98	2.95	3.75		
	28	N - 10⁵ cycles	1.00	2.00	3.00	3.30	3.60	3.70	3.75	
		dl/dN - 10⁻⁵ in/cycle	0.16	0.37	0.74	1.2	3.0	6.7	14	
		l - in	0.63	0.88	1.50	1.88	2.60	3.13	3.75	
Hiduminium 72	160	N - 10⁵ cycles	2.00	4.00	6.00	7.00	8.00	8.50	8.60	8.70
		dl/dN - 15⁵ in/cycle	0.08	0.13	0.29	0.43	0.96	2.0	3.5	9.5
		l - in	0.60	0.83	1.23	1.58	2.23	2.93	3.20	3.80
	162	N - 10⁵ cycles	2.00	4.00	6.00	7.00	8.00	8.10		
		dl/dN - 10⁻⁵ in/cycle	0.08	0.18	0.45	0.75	2.9	5.7		
		l - in	0.63	0.88	1.45	1.98	3.23	3.75		
2024-T81	170	N - 10⁵ cycles	2.00	4.00	6.00	8.00	8.20	8.40	8.60	8.80
		dl/dN - 10⁻⁵ in/cycle	0.07	0.12	0.28	0.72	0.74	0.94	1.5	4.1
		l - in	0.58	0.75	1.13	1.98	2.13	2.30	2.53	3.05
	172	N - 10⁵ cycles	2.00	4.00	6.00	6.20	6.40	6.60	6.70	
		dl/dN - 10⁻⁵ in/cycle	0.08	0.22	0.55	0.66	1.0	2.0	3.4	
		l - in	0.58	0.88	1.55	1.70	1.88	2.23	2.60	
X 2020	165	N - 10⁵ cycles	0.50	1.00	1.50	2.00	2.50	3.00	3.20	3.46
		dl/dN - 10⁻⁵ in/cycle	0.10	0.15	0.25	0.45	0.73	1.4	5.6	13
		l - in	0.55	0.63	0.70	0.88	1.18	1.65	2.15	2.40
	167	N - 10⁵ cycles	1.00	2.00	3.00	4.00	5.00	5.08		
		dl/dN - 10⁻⁵ in/cycle	0.06	0.09	0.24	0.47	2.6	8.7		
		l - in	0.53	0.63	0.85	1.23	2.23	2.60		
Hiduminium 54	228	N - 10⁵ cycles	2.00	4.00	6.00	8.00	10.00	11.00	11.40	
		dl/dN - 10⁻⁵ in/cycle	0.06	0.07	0.10	0.12	0.74	1.4	3.2	
		l - in	0.58	0.70	0.83	0.98	1.60	2.55	3.30	
	229	N - 10⁵ cycles	2.00	4.00	6.00	7.00	8.00	8.40	8.80	9.00
		dl/dN - 10⁻⁵ in/cycle	0.08	0.12	0.20	0.39	0.90	1.4	2.6	14
		l - in	0.65	0.83	1.13	1.38	2.00	2.48	3.10	4.20
DTD 687A	147	N - 10⁵ cycles	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.48
		dl/dN - 10⁻⁵ in/cycle	0.50	0.60	0.80	1.1	1.3	2.7	8.2	41
		l - in	0.58	0.68	0.83	1.00	1.23	1.60	2.48	3.40
	148	N - 10⁵ cycles	0.20	0.40	0.60	0.80	1.00	1.20	1.30	1.40
		dl/dN - 10⁻⁵ in/cycle	0.50	0.70	0.90	1.2	1.8	3.4	5.5	25
		l - in	0.53	0.68	0.83	1.03	1.28	1.73	2.18	3.25
DTD 5070	145	N - 10⁵ cycles	2.00	3.00	4.00	5.00	6.00	6.60	7.00	7.16
		dl/dN - 10⁻⁵ in/cycle	0.08	0.12	0.21	0.38	0.71	1.2	3.2	9.5
		l - in	0.63	0.73	0.90	1.18	1.73	2.30	3.10	4.10
	146	N - 10⁵ cycles	1.00	2.00	3.00	4.00	4.50	4.80	4.86	
		dl/dN - 10⁻⁵ in/cycle	0.11	0.21	0.51	1.0	2.0	3.8	19	
		l - in	0.55	0.70	1.08	1.85	2.55	3.33	3.80	
SAP	151	N - 10⁵ cycles	1.00	2.00	3.00	4.00	4.50	4.80	4.95	
		dl/dN - 10⁻⁵ in/cycle	0.07	0.10	0.14	0.33	1.4	4.6	29	
		l - in	0.55	0.65	0.78	0.98	1.28	2.03	3.80	
	152	N - 10⁵ cycles	1.00	2.00	3.00	3.50	3.80	3.90	4.00	
		dl/dN - 10⁻⁵ in/cycle	0.12	0.20	0.74	1.9	3.5	5.8	29	
		l - in	0.58	0.75	1.15	1.55	1.93	2.30	3.90	

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TABLE 4 - Results of crack propagation tests at 14000 ± 4000 psi

Material	Test No.		Cracking rate (dl/dN) and crack length(l) after N stress cycles							
DTD 546B	21	$N - 10^5$ cycles	0.20	0.40	0.60	0.70	0.75	0.80		
		$dl/dN - 10^{-5}$ in/cycle	0.70	1.7	3.4	5.2	10	31		
		1 - in	0.58	0.85	1.33	1.78	2.15	3.05		
	22	$N - 10^5$ cycles	0.20	0.40	0.60	0.68	0.76	0.78		
		$dl/dN - 10^{-5}$ in/cycle	0.58	1.6	3.7	6.6	18	48		
		1 - in	0.58	0.78	1.33	1.73	2.63	3.20		
Hiduminium 72	185	$N - 10^5$ cycles	0.20	0.60	1.00	1.30	1.50	1.52	1.54	1.58
		$dl/dN - 10^{-5}$ in/cycle	0.26	0.57	1.7	3.1	7.8	12	25	57
		1 - in	0.55	0.73	1.18	1.80	2.88	3.08	3.40	3.80
	187	$N - 10^5$ cycles	0.20	0.60	1.00	1.04	1.08	1.12	1.14	1.16
		$dl/dN - 10^{-5}$ in/cycle	0.35	1.3	4.7	5.1	7.1	10	14	41
		1 - in	0.58	0.90	1.88	2.13	2.35	2.70	2.93	3.35
2024-T81	177	$N - 10^5$ Cycles	0.20	0.30	0.40	0.45	0.47	0.48	0.49	
		$dl/dN - 10^{-5}$ in/cycle	1.2	2.6	7.3	13	17	24	42	
		1 - in	0.65	0.83	1.28	1.78	2.08	2.28	2.63	
Hiduminium 54	230	$N - 10^5$ cycles	0.20	0.40	0.60	0.80	1.00	1.10	1.14	1.16
		$dl/dN - 10^{-5}$ in/cycle	0.44	0.75	1.2	2.0	4.6	8.0	13	57
		1 - in	0.55	0.73	0.95	1.33	1.98	2.50	2.88	3.50
	231	$N - 10^5$ cycles	0.20	0.40	0.60	0.80	1.00	1.20	1.22	1.24
		$dl/dN - 10^{-5}$ in/cycle	0.70	0.90	1.6	2.0	3.0	13	15	32
		1 - in	0.58	0.73	0.90	1.23	1.63	2.78	3.05	3.50
DTD 5070	181	$N - 10^5$ cycles	0.20	0.40	0.60	0.80	0.90	0.92	0.94	0.95
		$dl/dN - 10^{-5}$ in/cycle	0.72	1.6	2.1	4.3	11	12	19	32
		1 - in	0.63	0.88	1.23	1.85	2.48	2.73	3.03	3.30
	182	$N - 10^5$ cycles	0.20	0.40	0.60	0.80	1.00	1.10	1.16	1.17
		$dl/dN - 10^{-5}$ in/cycle	0.54	0.63	0.79	1.4	3.6	8.0	19	27
		1 - in	0.60	0.73	0.88	1.10	1.58	2.13	2.85	3.13

TABLE 5 – Results of crack propagation tests at 18000 ± 2000 psi

Material	Test No.	Cracking rate (dl/dN) and crack length(l) after N stress cycles								
DTD 546B	58	$N - 10^5$ cycles	1.00	2.00	3.00	4.00	5.00			
		$dl/dN - 10^{-5}$ in/cycle	0.13	0.23	0.37	0.80	3.4			
		$l - in$	0.58	0.75	1.03	1.63	3.05			
	59	$N - 10^5$ cycles	1.00	2.00	3.00	4.00	5.00	6.00		
		$dl/dN - 10^{-5}$ in/cycle	0.10	0.14	0.18	0.30	0.69	3.1		
		$l - in$	0.55	0.65	0.78	0.98	1.45	2.78		
Hiduminium 72	159	$N - 10^5$ cycles	2.00	4.00	6.00	7.00	8.00	9.00	9.20	9.30
		$dl/dN - 10^{-5}$ in/cycle	0.06	0.11	0.20	0.30	0.48	1.2	2.4	5.2
		$l - in$	0.58	0.75	1.05	1.30	1.68	2.48	2.85	3.25
	161	$N - 10^5$ cycles	2.00	4.00	5.00	6.00	7.00	7.60	7.80	7.90
		$dl/dN - 10^{-5}$ in/cycle	0.08	0.17	0.27	0.43	0.78	1.8	3.5	12
		$l - in$	0.60	0.85	1.08	1.40	1.98	2.63	3.10	3.70
2024-T81	154	$N - 10^5$ cycles	1.50	2.00	2.50	3.00	3.50	3.80	3.90	3.97
		$dl/dN - 10^{-5}$ in/cycle	0.16	0.28	0.48	0.81	1.5	2.6	7.3	23
		$l - in$	0.63	0.73	0.93	1.25	1.80	2.40	3.00	3.30
	155	$N - 10^5$ cycles	1.50	2.00	2.50	2.80	3.00	3.30	3.40	3.45
		$dl/dN - 10^{-5}$ in/cycle	0.25	0.37	0.70	1.1	1.7	3.4	6.6	23
		$l - in$	0.75	0.93	1.18	1.43	1.68	2.35	2.80	3.40
DTD 687A	142	$N - 10^5$ cycles	0.20	0.40	0.50	0.60	0.70	0.76	0.80	0.83
		$dl/dN - 10^{-5}$ in/cycle	0.75	1.1	1.5	2.7	4.8	9.5	14	35
		$l - in$	0.63	0.83	0.93	1.13	1.53	1.98	2.40	3.00
	143	$N - 10^5$ cycles	0.20	0.30	0.40	0.50	0.60	0.65	0.70	0.71
		$dl/dN - 10^{-5}$ in/cycle	0.75	1.2	1.9	3.1	7.5	18	59	>100
		$l - in$	0.63	0.73	0.88	1.13	1.53	1.83	2.35	2.60
DTD 5070	81	$N - 10^5$ cycles	1.00	2.00	3.00	3.50	4.00	4.50	4.55	
		$dl/dN - 10^{-5}$ in/cycle	0.16	0.22	0.49	0.76	1.3	3.8	12	
		$l - in$	0.58	0.78	1.08	1.38	1.88	3.03	3.50	
	82	$N - 10^5$ cycles	1.00	2.00	3.00	3.50	4.00	4.30	4.38	
		$dl/dN - 10^{-5}$ in/cycle	0.18	0.29	0.64	0.93	1.5	4.7	30	
		$l - in$	0.63	0.83	1.28	1.68	2.30	2.98	3.60	
SAP	150	$N - 10^5$ cycles	1.00	2.00	3.00	3.10	3.20	3.25	3.30	
		$dl/dN - 10^{-5}$ in/cycle	0.17	0.34	1.5	2.8	4.6	11	48	
		$l - in$	0.68	0.93	1.50	1.65	1.98	2.40	3.50	
	153	$N - 10^5$ cycles	1.00	2.00	3.00	4.00	4.50	4.60	4.65	
		$dl/dN - 10^{-5}$ in/cycle	0.12	0.16	0.27	0.71	2.4	5.7	16	
		$l - in$	0.60	0.75	0.95	1.38	2.03	2.43	3.00	

TABLE 6 - Results of crack propagation tests at 18000 ± 4000 psi

Material	Test No.		Cracking rate (dl/dN) and crack length(l) after N stress cycles							
DTD 546B	42	N - 10^5 cycles	0.10	0.20	0.30	0.40	0.45	0.50	0.51	0.52
		dl/dN - 10^-5 in/cycle	1.1	1.5	2.3	4.2	5.4	14	20	70
		1 - in	0.60	0.73	0.88	1.15	1.45	2.0	2.23	2.55
	43	N - 10^5 cycles	0.10	0.30	0.50	0.60	0.62	0.64		
		dl/dN - 10^-5 in/cycle	0.85	1.5	4.6	11	15	54		
		1 - in	0.58	0.78	1.40	2.00	2.15	2.55		
Hiduminium 72	183	N - 10^5 cycles	0.20	0.40	0.60	0.80	0.90	1.00	1.02	1.04
		dl/dN - 10^-5 in/cycle	0.30	0.76	1.3	2.4	4.0	7.4	10	85
		1 - in.	0.60	0.75	0.90	1.23	1.53	2.00	2.23	3.00
	184	N - 10^5 cycles	0.20	0.40	0.60	0.80	1.10	1.12	1.14	1.15
		dl/dN - 10^-5 in/cycle	0.50	0.84	1.0	1.5	9.0	11	24	55
		1 - in	0.55	0.65	0.75	0.98	2.20	2.40	2.75	3.03
2024-T81	174	N - 10^5 cycles	0.10	0.20	0.40	0.60	0.62	0.64	0.66	0.67
		dl/dN - 10^-5 in/cycle	1.0	1.2	2.7	10	14	16	33	>100
		1 - in	0.53	0.60	0.85	1.60	1.75	1.90	2.25	2.70
	175	N - 10^5 cycles	0.10	0.20	0.30	0.40	0.42	0.44	0.45	
		dl/dN - 10^-5 in/cycle	0.58	1.00	2.2	6.0	7.6	9.5	17	
		1 - in	0.58	0.68	0.90	1.48	1.70	1.98	2.28	
X 2020	236	N - 10^5 cycles	0.05	0.10	0.125	0.15	0.175	0.20	0.21	0.215
		dl/dN - 10^-5 in/cycle	1.0	1.7	2.0	3.0	4.6	9.5	12	21
		1 - in	0.53	0.60	0.63	0.70	0.80	0.98	1.13	1.25
	237	N - 10^5 cycles	0.05	0.10	0.125	0.15	0.175	0.20	0.205	0.209
		dl/dN - 10^-5 in/cycle	1.0	2.0	3.0	5.0	9.0	15	23	>100
		1 - in	0.55	0.63	0.68	0.75	0.87	1.08	1.18	1.40
Hiduminium 54	234	N - 10^5 cycles	0.40	0.80	1.00	1.20	1.40	1.60	1.70	1.74
		dl/dN - 10^-5 in/cycle	0.58	1.1	1.2	1.8	2.7	4.6	9.8	90
		1 - in	0.68	1.00	1.20	1.53	2.03	2.68	3.28	4.00
	235	N - 10^5 cycles	0.20	0.60	0.80	1.20	1.40	1.50	1.58	1.59
		dl/dN - 10^-5 in/cycle	0.60	0.96	1.1	2.4	3.6	4.8	13	60
		1 - in	0.60	0.85	1.03	1.73	2.28	2.73	3.28	3.60
DTD 5070	91	N - 10^5 cycles	0.10	0.20	0.30	0.40	0.50	0.60		
		dl/dN - 10^-5 in/cycle	1.0	1.5	2.5	4.2	6.8	64		
		1 - in	0.58	0.70	0.88	1.15	1.63	2.80		
	93	N - 10^5 cycles	0.10	0.20	0.30	0.40	0.50	0.60	0.61	
		dl/dN - 10^-5 in/cycle	0.60	0.97	1.6	2.6	4.8	16	33	
		1 - in	0.53	0.58	0.75	1.00	1.43	2.40	2.65	

TABLE 7 - Results of room temperature crack propagation tests on 2024-T81 and DTD 5070 panels heated 1000 hours at 150°C

Material and stress cycle	Test No.		Cracking rate (dl/dN) and crack length(l) after N stress cycles							
2024-T81 14000 ± 2000 psi	205	N - 10^5 cycles	1.00	2.00	3.00	4.00	5.00	6.00	6.20	6.40
		dl/dN - 10^{-5} in/cycle	0.11	0.15	0.20	0.29	0.48	1.1	1.4	2.1
		l - in	0.60	0.73	0.88	1.05	1.40	2.18	2.40	2.75
	206	N - 10^5 cycles	1.00	2.00	3.00	4.00	5.00	6.00	7.00	7.50
		dl/dN - 10^{-5} in/cycle	0.02	0.03	0.06	0.09	0.15	0.35	0.90	1.6
		l - in	0.53	0.55	0.60	0.65	0.73	0.98	1.58	2.18
DTD 5070 14?00 ± 2000 psi	188	N - 10^5 cycles	1.00	2.00	3.00	4.00	5.00	6.00	7.00	7.50
		dl/dN - 10^{-5} in/cycle	0.07	0.11	0.14	0.19	0.28	0.50	1.2	3.9
		l - in	0.55	0.65	0.75	0.90	1.10	1.50	2.30	3.28
	189	N - 10^5 cycles	1.00	2.00	3.00	4.00	5.00	6.00	7.00	7.10
		dl/dN - 10^{-5} in/cycle	0.09	0.13	0.15	0.22	0.38	0.74	1.3	3.5
		l - in	0.58	0.68	0.80	0.98	1.30	1.80	2.95	3.20
2024-T81 14000 ± 4000 psi	208	N - 10^5 cycles	0.20	0.40	0.60	0.80	0.90	1.00		
		dl/dN - 10^{-5} in/cycle	0.45	1.0	1.4	2.9	4.2	22		
		l - in	0.53	0.65	0.85	1.28	1.63	2.58		
	209	N - 10^5 cycles	0.20	0.30	0.40	0.50	0.60	0.70		
		dl/dN - 10^{-5} in/cycle	0.80	1.2	1.7	2.6	4.4	22		
		l - in	0.60	0.68	0.80	1.03	1.38	2.20		
DTD 5070 14000 ± 4000 psi	190	N - 10^5 cycles	0.20	0.40	0.60	0.80	1.00	1.10	1.14	1.16
		dl/dN - 10^{-5} in/cycle	0.50	0.75	1.1	1.7	3.3	5.3	8.4	22
		l - in	0.60	0.70	0.88	1.15	1.65	2.08	2.38	2.70
	191	N - 10^5 cycles	0.20	0.40	0.60	0.80	0.84	0.86	0.88	
		dl/dN - 10^{-5} in/cycle	0.56	1.1	2.1	3.0	4.9	6.5	13	
		l - in	0.58	0.78	1.10	1.35	1.78	1.98	2.30	

TABLE 8 - Results of 150°C crack propagation tests on 2024-T81 and DTD 5070 panels heated 1000 hours at 150°C

Material and stress cycle	Test No.		Cracking rate (dl/dN) and crack length(l) after N stress cycles							
2024-T81 14000 ± 2000 psi	210	$N - 10^5$ cycles	2.00	4.00	6.00	7.00	8.00	8.40	8.80	
		$dl/dN - 10^{-5}$ in/cycle	0.07	0.15	0.32	0.50	0.86	1.3	4.4	
		l - in	0.63	0.80	1.23	1.63	2.25	2.65	3.50	
	214	$N - 10^5$ cycles	2.00	4.00	6.00	8.00	10.00	11.00	12.00	12.10
		$dl/dN - 10^{-5}$ in/cycle	0.04	0.06	0.11	0.18	0.36	0.56	2.6	4.7
		l - in	0.58	0.65	0.80	1.05	1.53	1.98	3.08	3.50
DTD 5070 14000 ± 2000 psi	193	$N - 10^5$ cycles	2.00	4.00	6.00	7.00	8.00	8.60		
		$dl/dN - 10^{-5}$ in/cycle	0.08	0.13	0.29	0.47	0.80	2.9		
		l - in	0.65	0.83	1.23	1.63	2.23	3.03		
	195	$N - 10^5$ cycles	1.00	2.00	3.00	4.00	5.00	6.00	6.50	6.90
		$dl/dN - 10^{-5}$ in/cycle	0.05	0.09	0.16	0.26	0.39	0.60	0.84	4.9
		l - in	0.58	0.65	0.78	1.00	1.30	1.75	2.10	3.40
2024-T81 14000 ± 4000 psi	211	$N - 10^5$ cycles	0.20	0.40	0.60	0.80	0.90	0.94	0.98	
		$dl/dN - 10^{-5}$ in/cycle	0.64	1.1	1.9	4.0	8.3	15	57	
		l - in	0.60	0.78	1.08	1.55	2.10	2.55	3.65	
	212	$N - 10^5$ cycles	0.20	0.40	0.60	0.80	0.90	1.00	1.20	
		$dl/dN - 10^{-5}$ in/cycle	0.31	0.51	1.1	3.3	6.2	15	57	
		l - in	0.55	0.65	0.83	1.28	1.75	3.05	3.95	
DTD 5070 14000 ± 4000 psi	194	$N - 10^5$ cycles	0.20	0.40	0.60	0.80	1.00			
		$dl/dN - 10^{-5}$ in/cycle	0.39	0.84	1.5	2.8	9.0			
		l - in	0.55	0.70	0.95	1.35	2.38			
	196	$N - 10^5$ cycles	0.20	0.40	0.60	0.80	1.00	1.20		
		$dl/dN - 10^{-5}$ in/cycle	0.48	0.72	1.1	1.8	3.0	9.0		
		l - in	0.58	0.70	0.90	1.20	1.63	2.60		

TABLE 9 - Crack propagation rates (10^{-5} in/cycle) at 1" crack lengths

Material	Condition	Test temperature	Stress cycle-psi 14000 ±2000	14000 ±4000	18000 ±2000	18000 ±4000
DTD 546B	As received	RT	0.41	2.2	0.34	2.8
Hiduminium 72	" "	"	0.20	1.35	0.20	1.55
2024-T81	" "	"	0.24	4.2	0.50	3.3
" "	Heated 1000 hours at 150°C	"	0.28	2.0		
" "	" "	150°C	0.20	2.0		
X2020	As received	RT	0.45			10.5
Hiduminium 54	" "	"	0.16	1.5		1.1
DTD 687A	" "	"	1.1		2.3	
DTD 5070	" "	"	0.36	1.3	0.38	2.7
"	Heated 1000 hours at 150°C	"	0.22	1.6		
"	" "	150°C	0.20	1.45		
SAP	As received	RT	0.50		0.36	

TABLE 10 — Residual strengths of cracked panels

Material	Crack length -in	Crack length/ panel width	Failing load -tons	Residual strength -tsi of gross area	Residual strength/ Uncracked TS
DTD 546B	0.48	0.08	9.1	22.9	79.0
	1.00	0.15	7.8	19.6	68.0
	1.33	0.20	6.8	17.0	59.0
	1.73	0.27	5.6	13.9	48.0
	2.53	0.39	4.5	11.2	39.0
	3.20	0.49	3.6	8.7	30.3
	4.13	0.64	2.7	6.6	23.0
	4.63	0.72	1.9	4.7	16.2
Hiduminium 72	0.50	0.08	8.5	21.7	73.0
	1.00	0.16	7.8	18.8	63.5
	1.95	0.30	6.1	15.0	50.5
	2.83	0.44	4.5	11.1	37.5
2024-T81	0.50	0.08	8.1	19.9	64.0
	0.95	0.14	6.2	15.3	48.8
	1.23	0.19	5.5	15.1	48.2
	1.45	0.23	5.4	13.3	42.2
	1.93	0.30	5.4	13.4	42.5
	2.33	0.36	4.6	11.3	36.0
	2.83	0.43	3.7	8.9	28.4
	3.30	0.51	3.0	7.3	23.0
	4.25	0.65	2.6	6.3	20.0
	4.40	0.68	2.0	4.8	15.2
X 2020	0.50	0.08	4.7	14.1	43.2
	1.00	0.15	3.3	10.8	33.2
	1.48	0.23	2.9	10.2	31.3
	2.05	0.32	2.6	10.4	32.0
Hiduminium 54	0.50	0.08	8.2	19.0	74.0
	0.70	0.11	7.9	18.1	71.0
	1.05	0.16	7.2	16.7	65.0
	1.55	0.24	6.5	15.2	59.0
	2.55	0.39	4.8	11.2	43.5
DTD 687A	0.48	0.07	8.1	20.1	55.0
	1.38	0.21	4.8	12.0	32.9
	2.35	0.36	4.3	10.6	29.1
	2.45	0.38	4.2	10.3	28.2
DTD 5070	0.50	0.08	7.9	19.9	76.0
	0.80	0.12	7.1	17.9	68.0
	1.55	0.24	5.9	14.8	57.0
	2.05	0.31	4.8	11.9	46.0
	2.85	0.44	3.5	8.8	33.0
	3.70	0.57	3.1	7.3	28.0
	4.08	0.63	2.4	6.0	23.0
SAP	0.50	0.08	8.0	18.7	73.5
	1.00	0.16	6.7	14.7	61.8
	1.53	0.24	6.1	13.5	56.8
	2.55	0.39	4.5	10.5	44.5

TABLE 11 – Residual strengths of DTD 546B panels which
broke in the fatigue machine

Test No.	Crack length at failure - in	Crack length/ panel width	Stress cycle[1] -psi	Peak stress[2] -psi	Residual strength[3]/ Uncracked TS
71	5.10	0.78	6000 ± 2000	7400	0.12
72	5.30	0.81	6000 ± 2000	7400	0.12
70	5.03	0.77	8000 ± 2000	9250	0.14
67	4.53	0.70	10000 ± 2000	11100	0.17
68	4.53	0.70	10000 ± 2000	11100	0.17
46	3.98	0.61	14000 ± 1000	13850	0.22
27	3.88	0.60	14000 ± 2000	14800	0.23
28	4.38	0.67	14000 ± 2000	14800	0.23
34	4.00	0.62	12000 ± 5000	15700	0.24
35	3.90	0.60	12000 ± 5000	15700	0.24
21	4.05	0.63	14000 ± 4000	16600	0.26
22	3.70	0.57	14000 ± 4000	16600	0.26
30	3.53	0.54	14000 ± 6000	18500	0.29
31	3.45	0.53	14000 ± 6000	18500	0.29

[1] Calculated on initial cross-sectional area at slot line

[2] Calculated on full cross-sectional area of panel

[3] Assumed equal to peak stress of fatigue cycle

TABLE 12 - Residual strengths of panels containing 1" long cracks

Material	Residual strength -tsi of gross area	Residual strength/ Uncracked TS
DTD 546B	19.2	0.67
Hiduminium 72	19.3	0.65
2024-T81	19.0	0.60
X 2020	12.1	0.37
Hiduminium 54	17.2	0.67
DTD 687A	16.0	0.44
DTD 5070	16.7	0.64
SAP	15.2	0.64

TABLE 13 - Results of crack propagation tests on 4½" wide panels

Material and stress cycle	Test No.												
			Cracking rate (dl/dN) and crack length(l) after N stress cycles										
DTD 546B	219	N - 10⁵ cycles	2.00	4.00	6.00	8.00	10.00	11.00	11.50	11.56			
		dl/dN - 10⁻⁵ in/cycle	0.01	0.02	0.04	0.13	0.39	0.98	3.8	14.			
		l - in	0.50	0.55	0.63	0.78	1.25	1.90	2.80	3.10			
14000 ± 2000 psi	220	N - 10⁵ cycles	2.00	4.00	6.00	8.00	10.00	11.00	12.00	12.40	12.80	12.90	
		dl/dN - 10⁻⁵ in/cycle	0.04	0.05	0.06	0.08	0.14	0.23	0.43	0.62	2.3	5.9	
		l - in	0.58	0.68	0.80	0.95	1.15	1.35	1.65	1.85	2.33	2.80	
DTD 546B	221	N - 10⁵ cycles	0.10	0.20	0.40	0.60	0.70	0.80	0.84	0.86	0.87		
		dl/dN - 10⁻⁵ in/cycle	0.61	0.77	1.1	2.3	3.4	5.4	11	19	48		
		l - in	0.55	0.63	0.80	1.13	1.40	1.85	2.18	2.48	2.85		
14000 ± 4000 psi	222	N - 10⁵ cycles	0.10	0.20	0.40	0.60	0.70	0.80	0.82				
		dl/dN - 10⁻⁵ in/cycle	0.56	0.82	1.3	2.7	4.3	14	57				
		l - in	0.55	0.63	0.85	1.23	1.55	2.38	2.90				
DTD 5070	215	N - 10⁵ cycles	2.00	4.00	6.00	8.00	9.00	10.00	10.40	10.80	10.90		
		dl/dN - 10⁻⁵ in/cycle	0.03	0.04	0.05	0.12	0.29	0.71	1.1	2.2	4.0		
		l - in	0.53	0.60	0.68	0.83	1.03	1.50	1.85	2.43	2.75		
14000 ± 2000 psi	216	N - 10⁵ cycles	2.00	4.00	6.00	8.00	9.00	10.00	11.00	12.00	12.40		
		dl/dN - 10⁻⁵ in/cycle	0.03	0.04	0.05	0.07	0.14	0.22	0.40	0.94	14		
		l - in	0.58	0.65	0.75	0.85	6.95	1.15	1.45	2.03	3.00		
DTD 5070	217	N - 10⁵ cycles	0.20	0.40	0.60	0.80	0.90	0.94					
		dl/dN - 10⁻⁵ in/cycle	0.56	1.5	1.6	3.4	7.6	57					
		l - in	0.60	0.75	1.03	1.55	2.08	2.85					
14000 ± 4000 psi	218	N - 10⁵ cycles	0.20	0.40	0.60	0.80	1.00	1.10	1.20	1.30	1.35		
		dl/dN - 10⁻⁵ in/cycle	0.42	0.52	0.70	1.1	1.6	2.3	3.8	6.6	18		
		l - in	0.58	0.68	0.80	0.95	1.23	1.43	1.73	2.23	2.85		

TABLE 14 - Results of crack propagation tests on 6¼" wide DTD 546B panels with stress cycles of 6000 ± 2000 psi, 8000 ± 2000 psi and 10 000 ± 2000 psi

Stress cycle -psi	Test No.		Cracking rate (dl/dN) and crack length(l) after N stress cycles							
6000 ± 2000	71	$N - 10^5$ cycles	1.00	2.00	3.00	4.00	5.00	5.50	5.90	
		$dl/dN - 10^{-5}$ in/cycle	0.13	0.21	0.26	0.46	1.2	1.9	6.5	
		$l - $ in	0.53	0.60	0.93	1.28	2.05	2.80	4.00	
	72	$N - 10^5$ cycles	2.00	3.00	4.00	5.00	6.00	7.00	7.80	
		$dl/dN - 10^{-5}$ in/cycle	0.05	0.10	0.18	0.35	0.63	1.2	12	
		$l - $ in	0.58	0.65	0.78	1.05	1.53	2.40	4.00	
8000 ± 2000	70	$N - 10^5$ cycles	1.00	2.00	3.00	3.50	4.00	4.50	5.00	5.30
		$dl/dN - 10^{-5}$ in/cycle	0.11	0.21	0.40	0.59	0.89	1.3	2.1	3.8
		$l - $ in	0.55	0.70	1.00	1.25	1.60	2.13	2.98	3.75
10000 ± 2000	67	$N - 10^5$ cycles	1.00	2.00	3.00	4.00	4.50	5.00	5.50	5.90
		$dl/dN - 10^{-5}$ in/cycle	0.10	0.13	0.23	0.33	0.45	0.93	1.7	4.5
		$l - $ in	0.60	0.70	0.88	1.15	1.33	1.63	2.28	3.40
	68	$N - 10^5$ cycles	1.00	2.00	3.00	4.00	5.00	6.00	6.20	6.40
		$dl/dN - 10^{-5}$ in/cycle	0.07	0.12	0.22	0.36	0.73	1.7	2.5	8.2
		$l - $ in	0.55	0.65	0.80	1.09	1.60	2.78	3.20	4.10

TABLE 15 - Results of crack propagation tests on 6½" wide DTD 546B panels with stress cycles of 14000 ± 1000 psi, 14000 ± 3000 psi and 14000 ± 6000 psi

Stress cycle psi	Test No.		Cracking rate (dl/dN) and crack length(l) after N stress cycles						
14000 ± 1000	46	$N - 10^5$ cycles	10.0	20.0	25.0	27.5	30.0	32.0	33.8
		$dl/dN - 10^{-5}$ in/cycle	0.025	0.042	0.083	0.13	0.26	0.45	2.1
		l - in	0.65	0.98	1.25	1.53	1.98	2.65	3.80
14000 ± 3000	23	$N - 10^5$ cycles	0.50	1.00	1.25	1.50	1.60	1.62	
		$dl/dN - 10^{-5}$ in/cycle	0.66	0.99	2.3	5.1	11	42	
		l - in	0.70	1.08	1.45	2.30	3.03	3.53	
	24	$N - 10^5$ cycles	0.50	1.00	1.25	1.40	1.50	1.70	
		$dl/dN - 10^{-5}$ in/cycle	0.69	1.3	2.0	3.7	5.6	16	
		l - in	0.68	1.13	1.53	1.95	2.43	3.23	
14000 ± 6000	30	$N - 10^5$ cycles	0.10	0.15	0.20	0.23	0.24	0.25	
		$dl/dN - 10^{-5}$ in/cycle	3.0	4.9	12	21	34	56	
		l - in	0.75	0.93	1.33	1.70	2.13	2.15	
	31	$N - 10^5$ cycles	0.10	0.15	0.20	0.23	0.25	0.26	
		$dl/dN - 10^{-5}$ in/cycle	2.9	5.3	10	14	34	70	
		l - in	0.75	0.93	1.33	1.63	2.15	2.68	

REFERENCES

No.	Author	Title, etc.,
1	B.F. Billing	A null method for the measurement of load in axial fatigue testing machines. Journal of the Royal Aeronautical Society, <u>58</u>, 508-509, 1954.
2	D.P. Rooke N.J.F. Gunn J.T. Ballett F.J. Bradshaw	Crack propagation in fatigue. Some experiments with DTD.5070A aluminium alloy sheet. R.A.E. Tech. Report No.64025, October 1964.

SLOT CENTRALLY
LOCATED IN PANEL

·50"

0·007"

$\frac{1}{8}$" DIA HOLES

SCALE $\frac{1}{2}$

CRACK PROPAGATION PANEL

6·0"

1·0"RAD

2·5"
PARALLEL

8·0"

1·5"

SCALE $\frac{1}{2}$
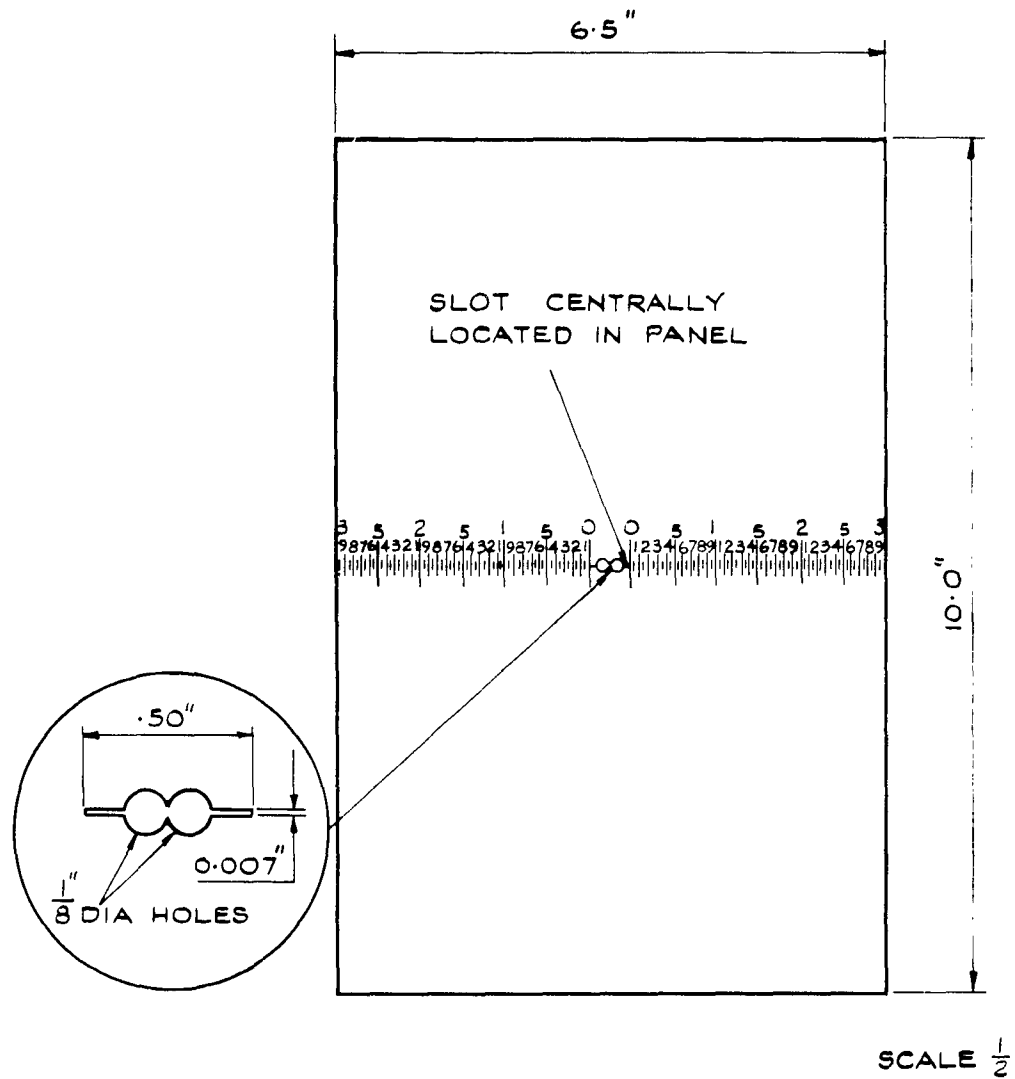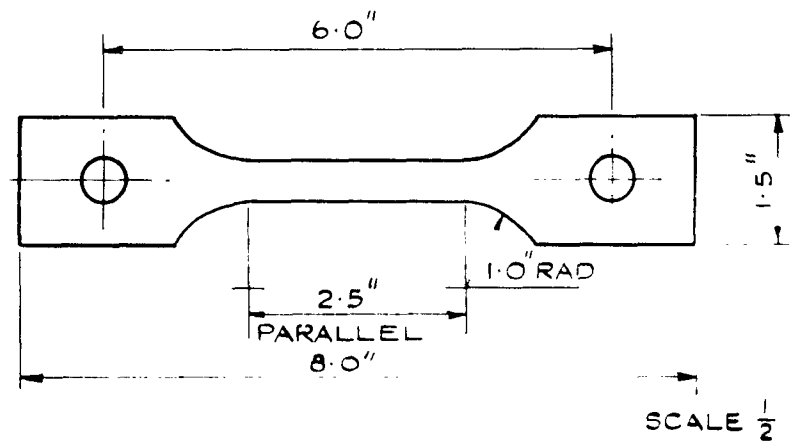
TENSILE TEST PIECE

FIG. 1 TEST PIECES
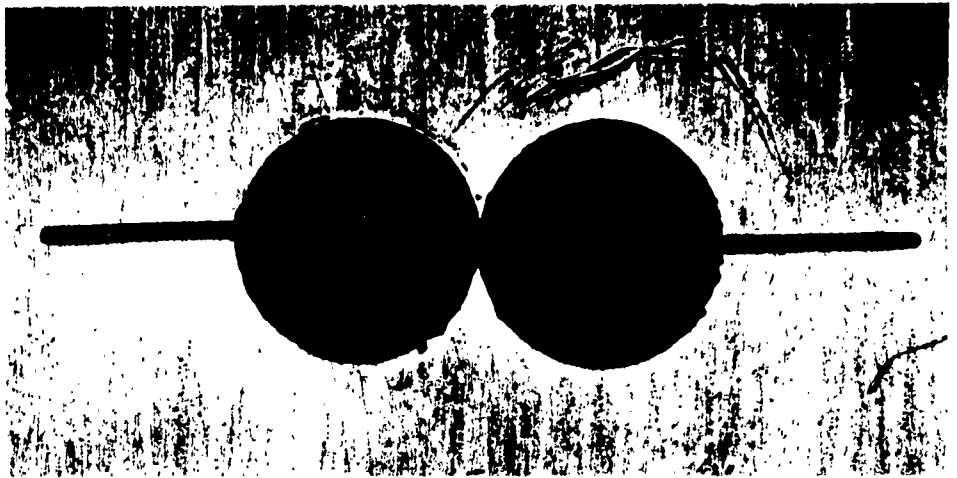
Fig.2

X 10
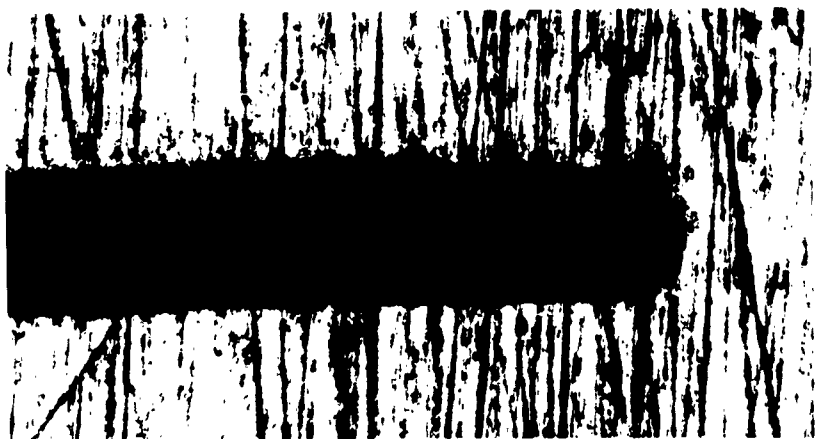
X 100

Fig. 2 Photomicrographs of the Slot
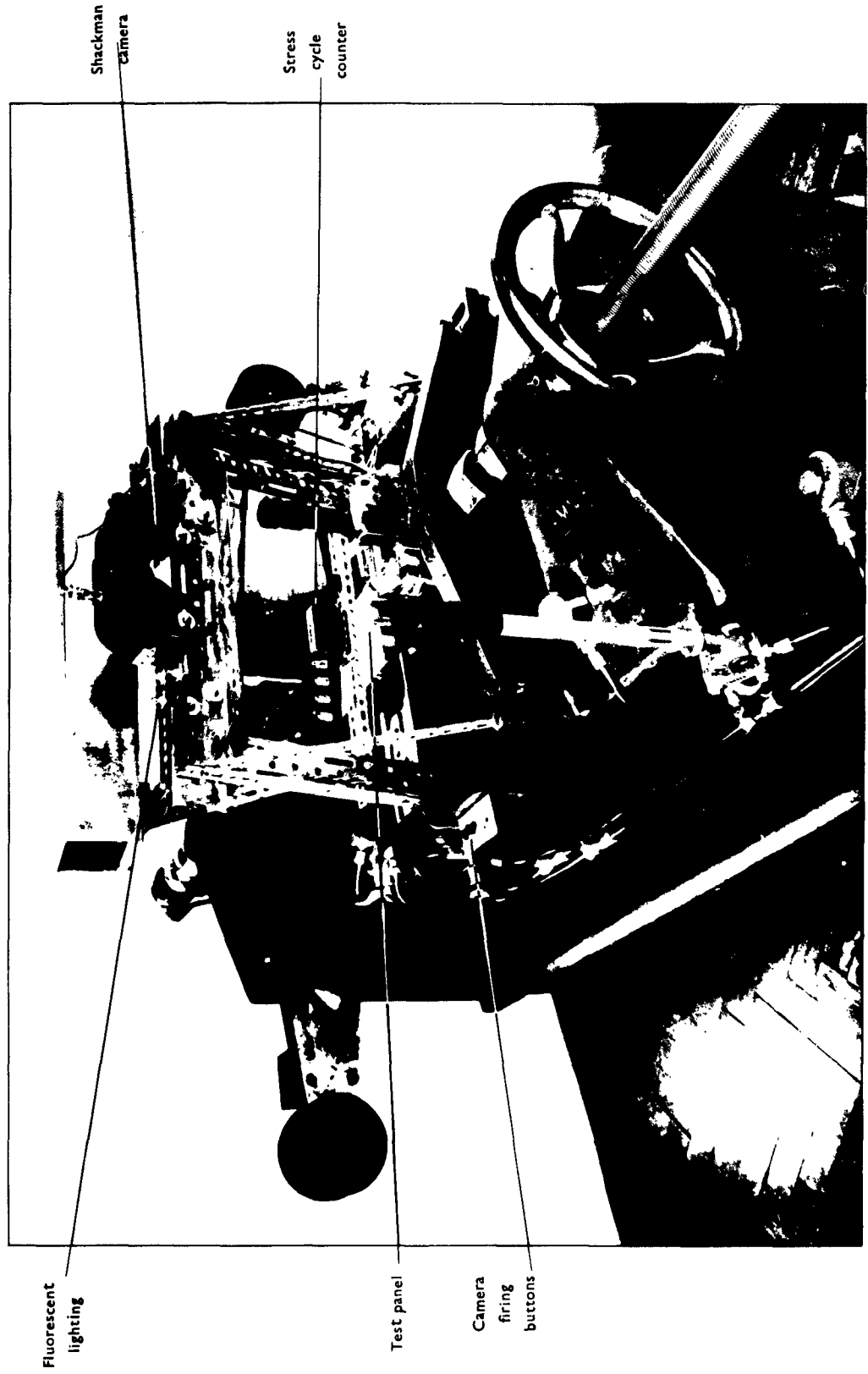
Fig.3

Fig. 3 6 Ton Schenck Pulsator with 6½ins. panel in position

R. 64024

Fig.4   CPM/R/471
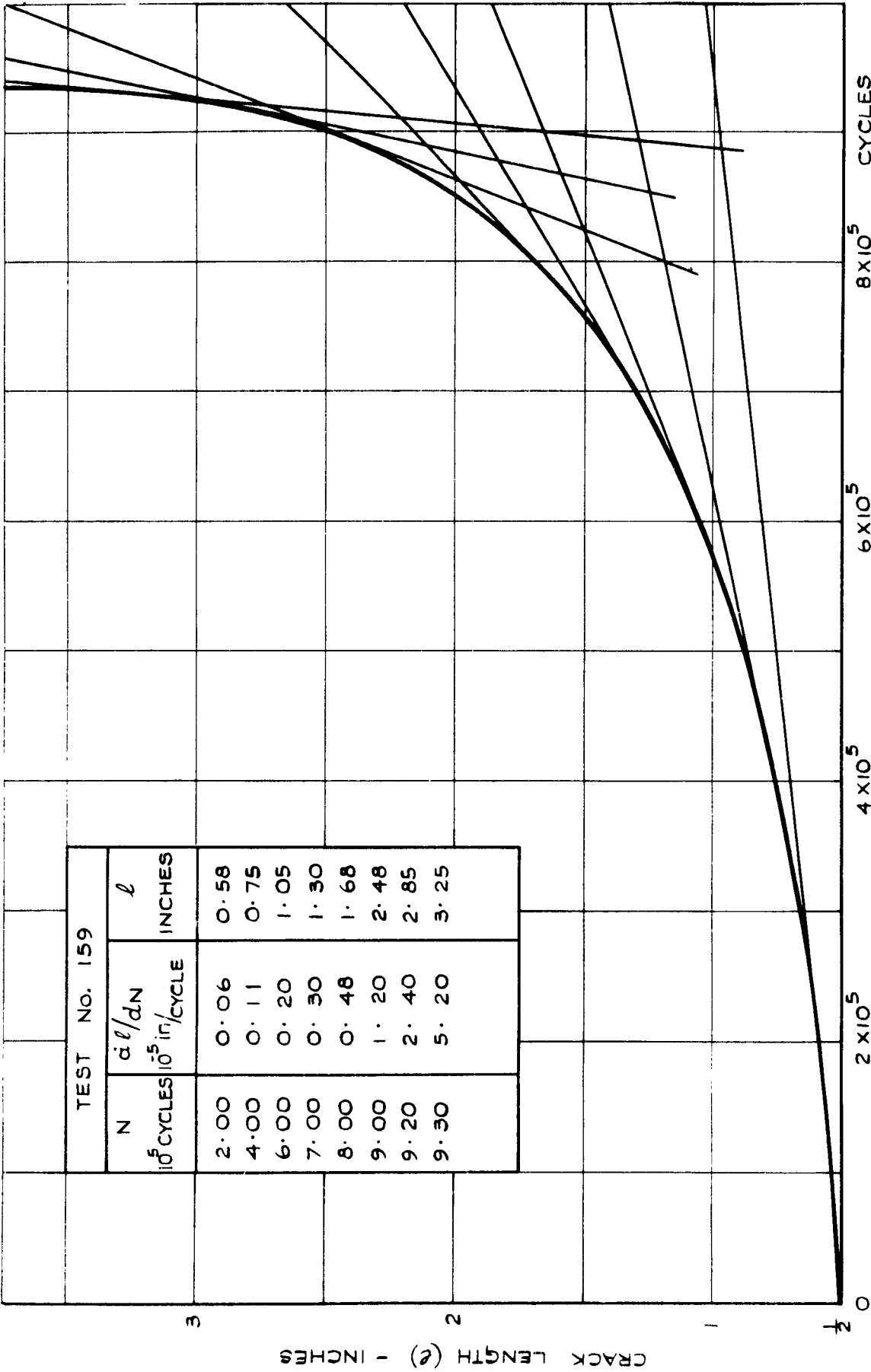
FIG.4 RELATION BETWEEN CRACK LENGTH & NUMBER OF STRESS CYCLES
FOR A HIDUMINIUM 72 PANEL STRESSED AT 18000 ± 2000 psi

TEST No. 159		
N 10^5 CYCLES	$\frac{d\ell}{dN}$ 10^{-5} in/CYCLE	ℓ INCHES
2·00	0·06	0·58
4·00	0·11	0·75
6·00	0·20	1·05
7·00	0·30	1·30
8·00	0·48	1·68
9·00	1·20	2·48
9·20	2·40	2·85
9·30	5·20	3·25

CRACK LENGTH (ℓ) – INCHES

TEST NO. 161		
N 10^5 CYCLES	$d\ell/dN$ 10^{-5} in/CYCLE	ℓ INCHES
2.00	0.08	0.60
4.00	0.17	0.85
5.00	0.27	1.08
6.00	0.43	1.40
7.00	0.78	1.98
7.50	1.37	2.49
7.60	1.80	2.65
7.80	3.50	3.10
7.90	12.0	5.70

CRACK LENGTH (ℓ) –INCHES

2×10^5 4×10^5 6×10^5 8×10^5 CYCLES
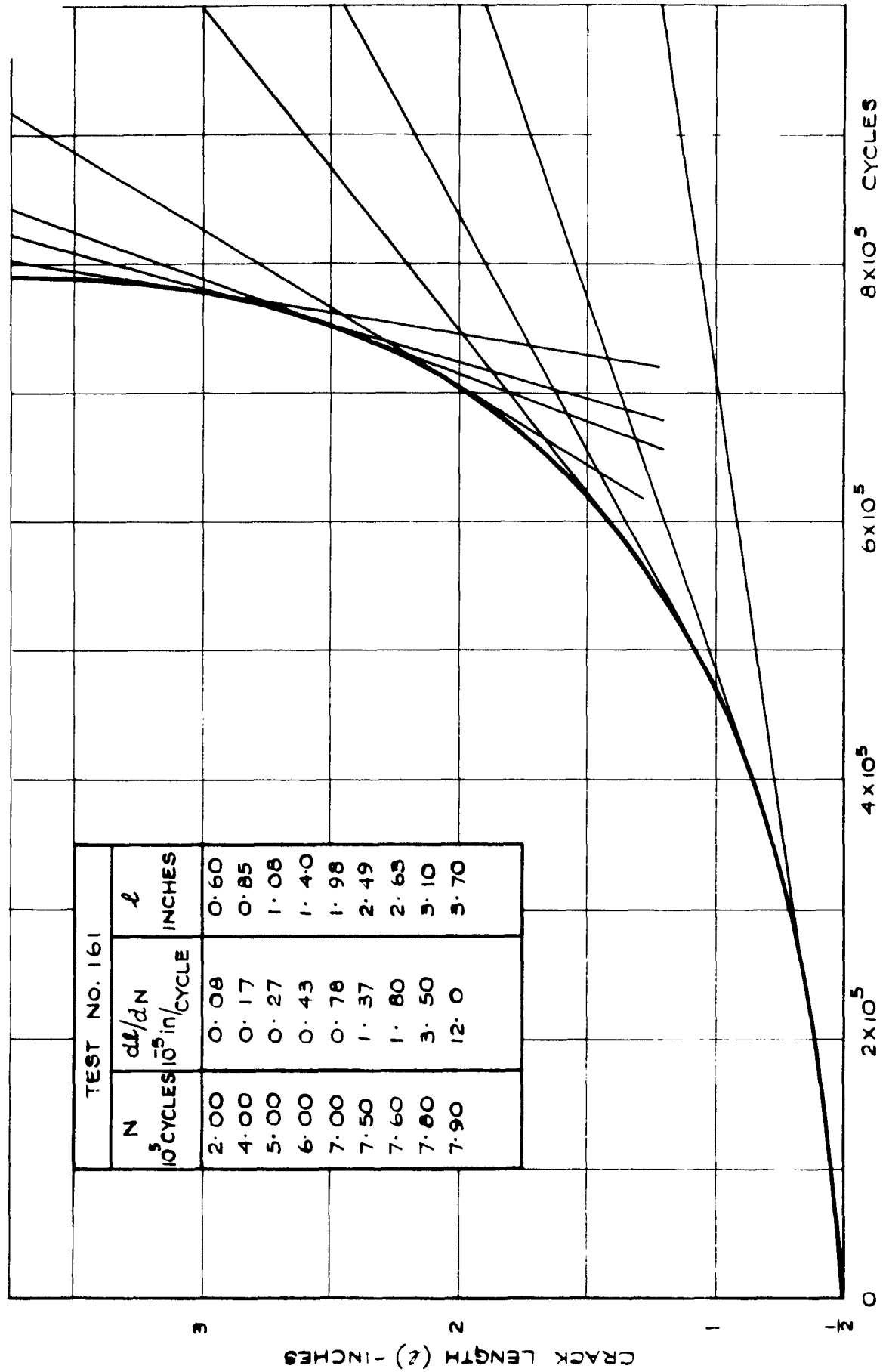
FIG.5 RELATION BETWEEN CRACK LENGTH & NUMBER OF STRESS CYCLES FROM A HIDUMINIUM 72 PANEL STRESSED AT 18000±2000 psi

Fig.6   CPM/ R /473
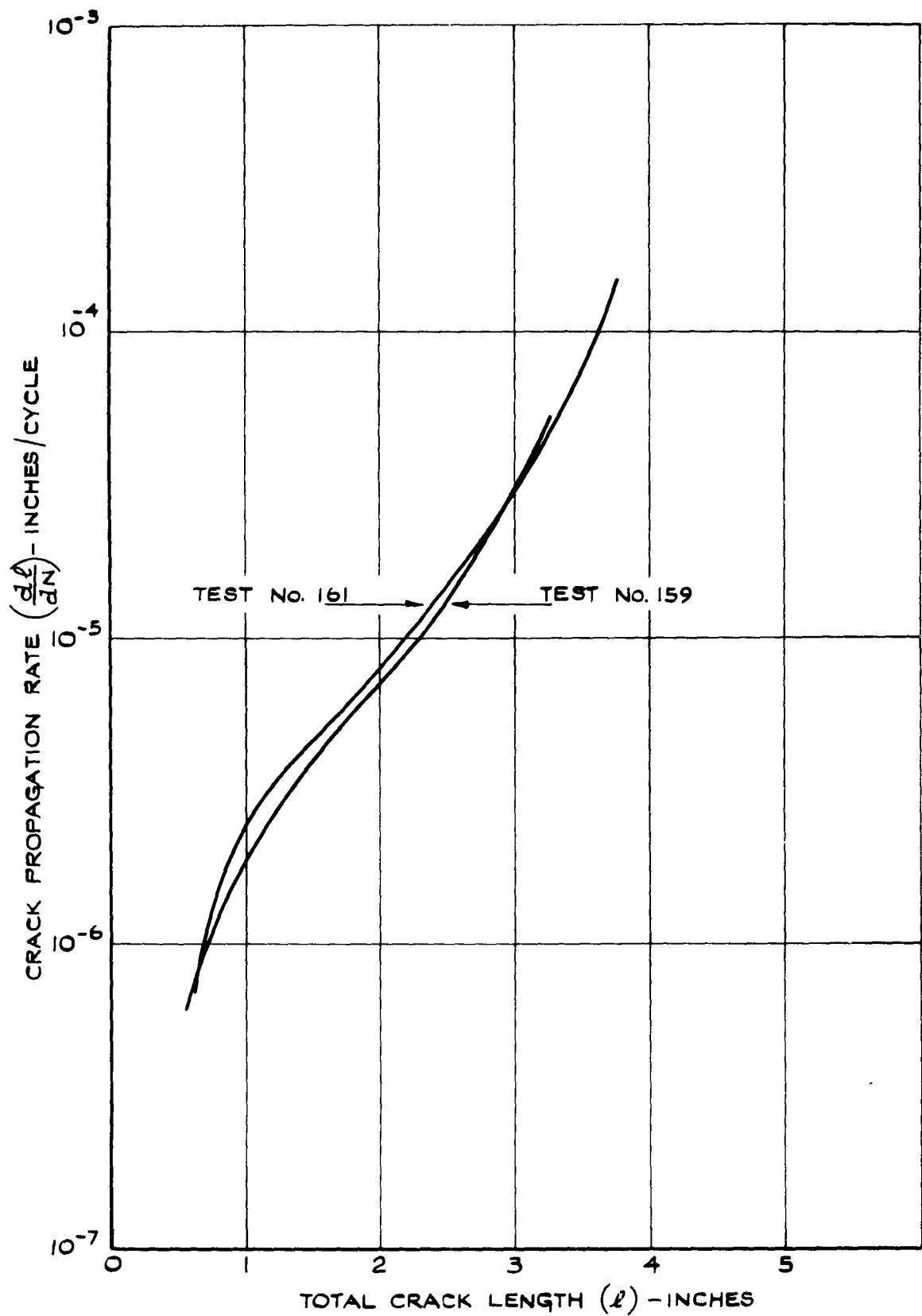
FIG.6 RELATION BETWEEN CRACK PROPAGATION RATES
& CRACK LENGTHS FOR TWO HIDUMINIUM 72 PANELS
STRESSED   AT   18000 ± 2000 psi
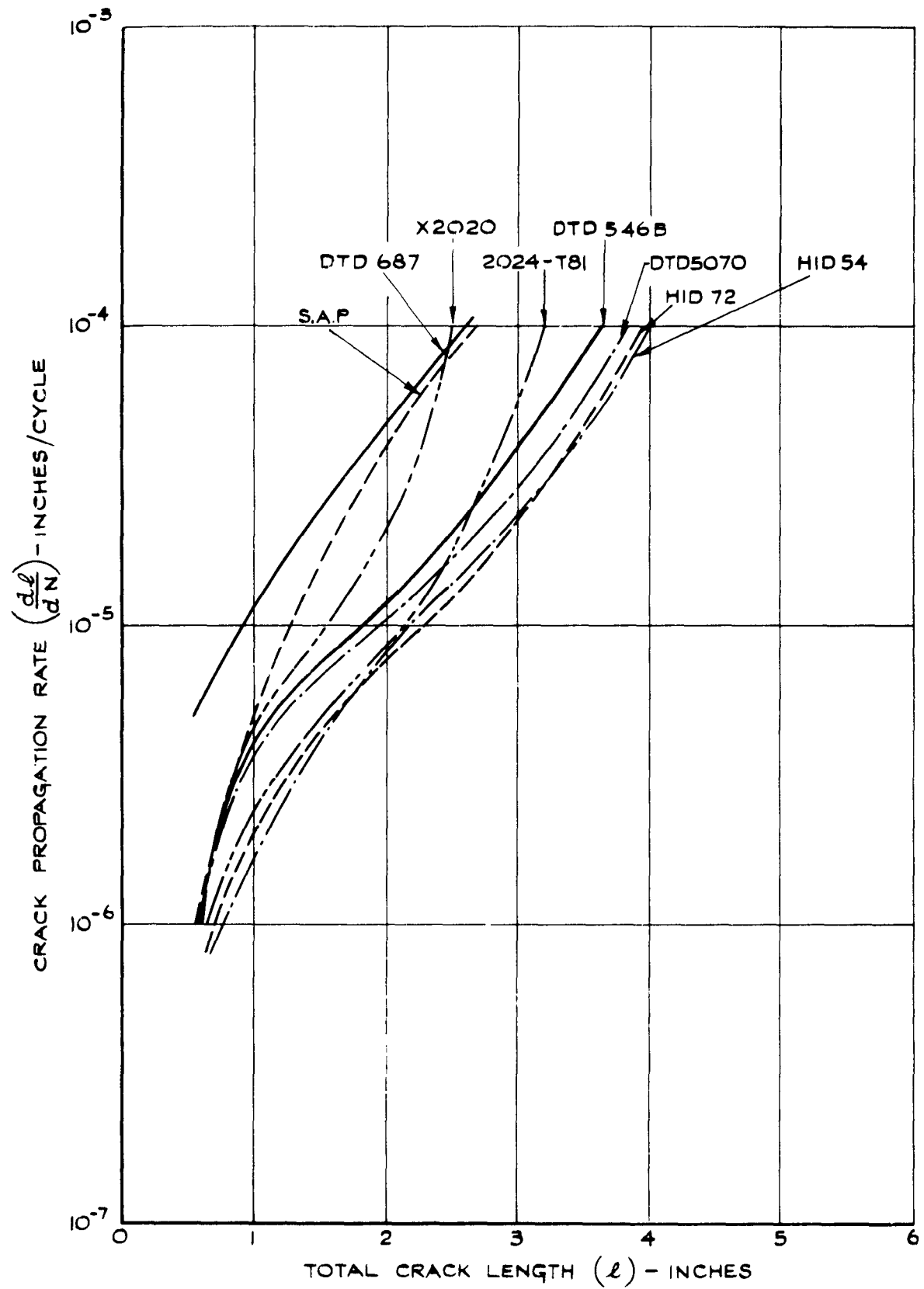
FIG. 7   RESULTS OF CRACK PROPAGATION TESTS WITH A
STRESS CYCLE OF 14000 ± 2000 psi

Fig.8 CPM/R/475
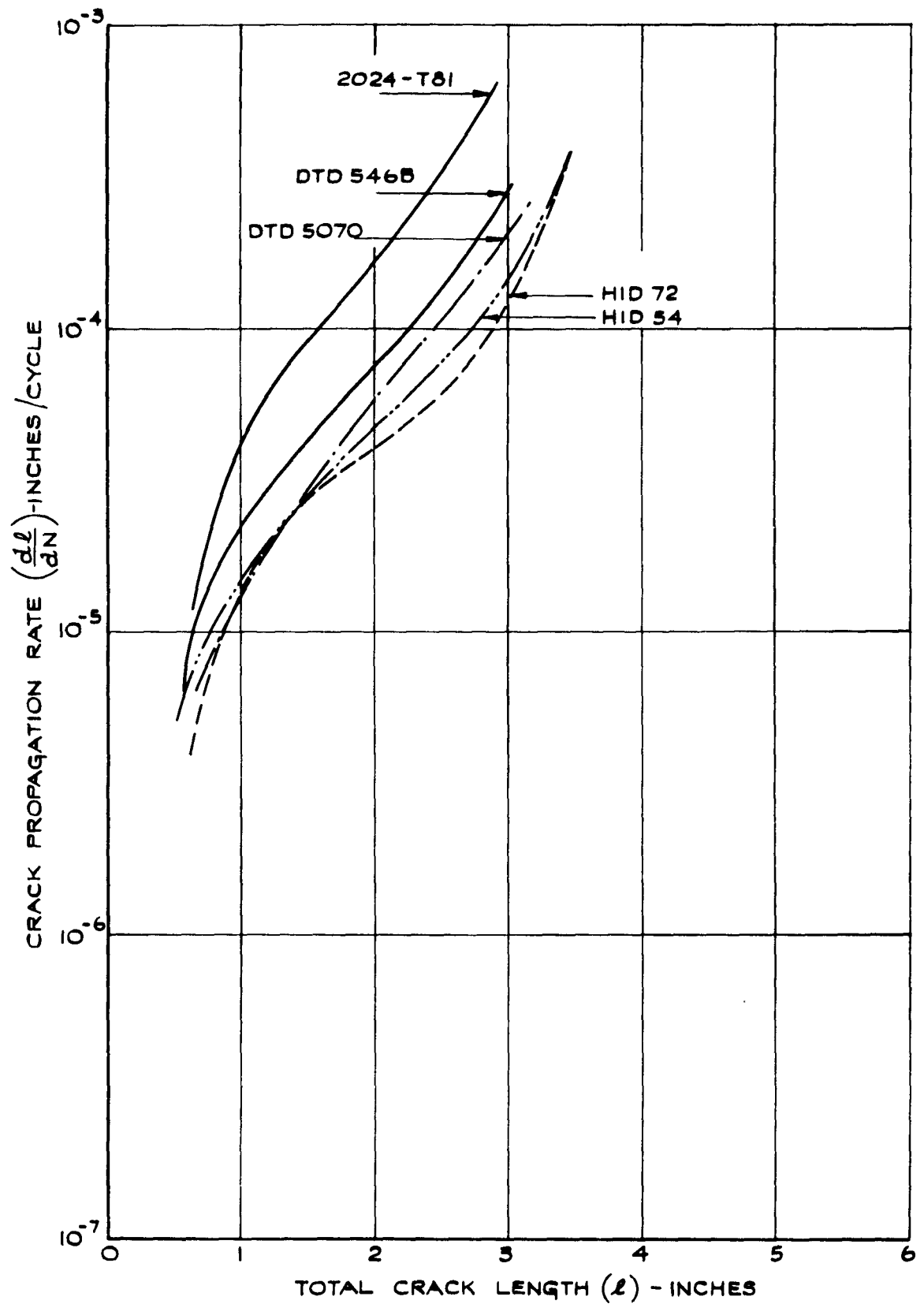
FIG. 8 RESULTS OF CRACK PROPAGATION TESTS WITH A STRESS CYCLE OF 14000 ± 4000 psi
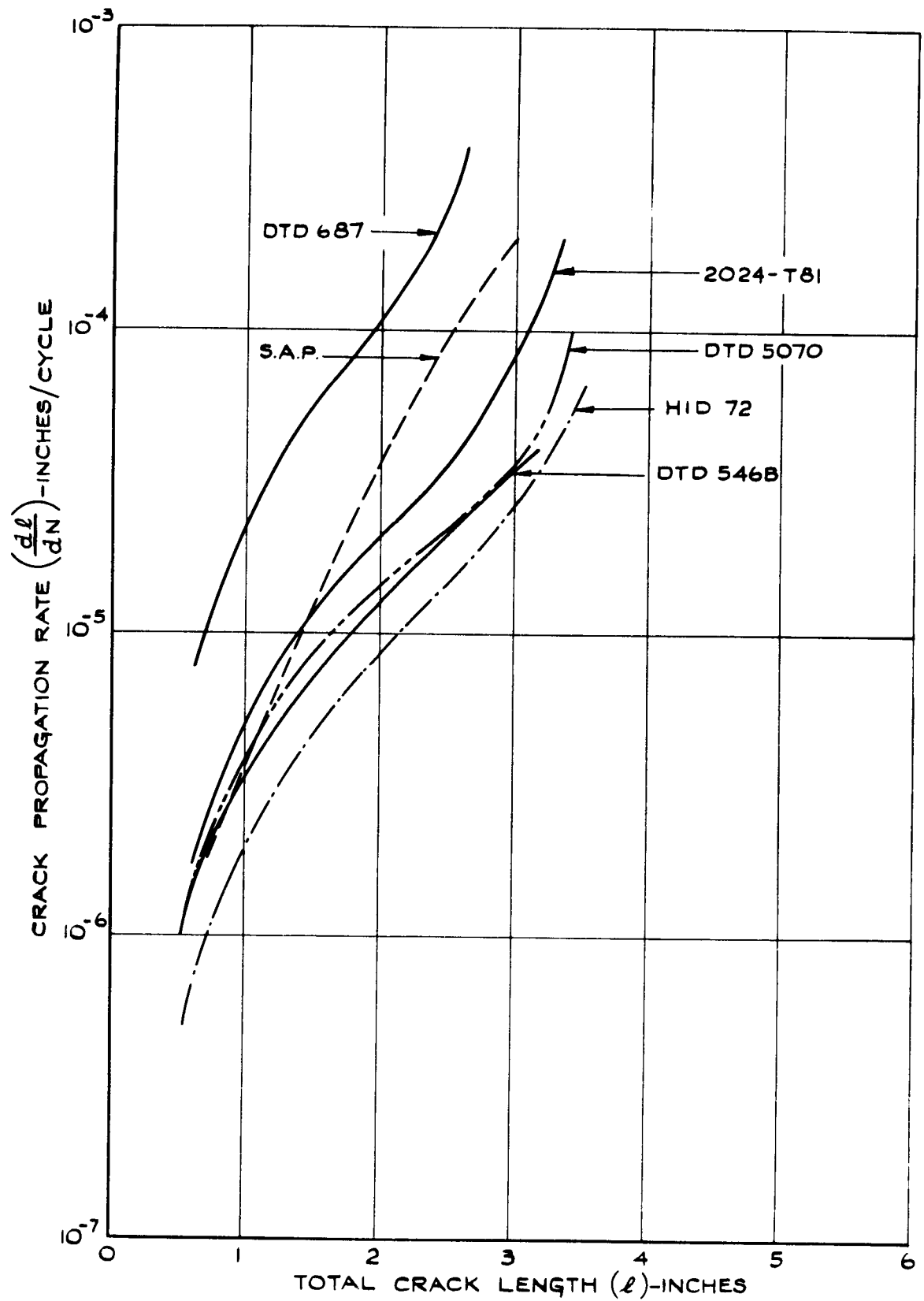
FIG. 9. RESULTS OF CRACK PROPAGATION TESTS WITH A
STRESS CYCLE OF 18000 ± 2000 psi

Fig.10   CPM/R/477
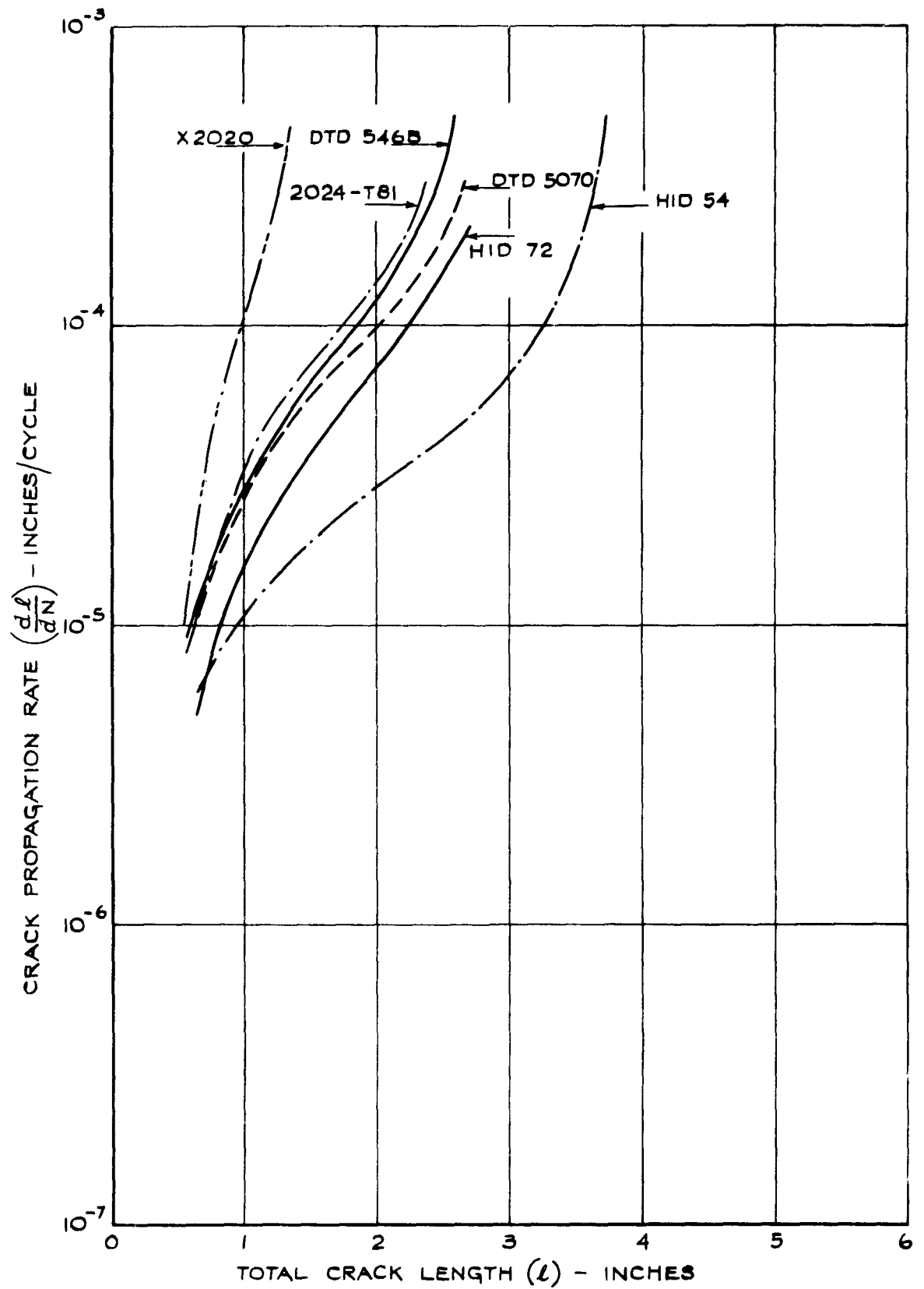
FIG.10   RESULTS OF CRACK PROPAGATION TESTS WITH A
STRESS CYCLE OF 18000 ± 4000 psi
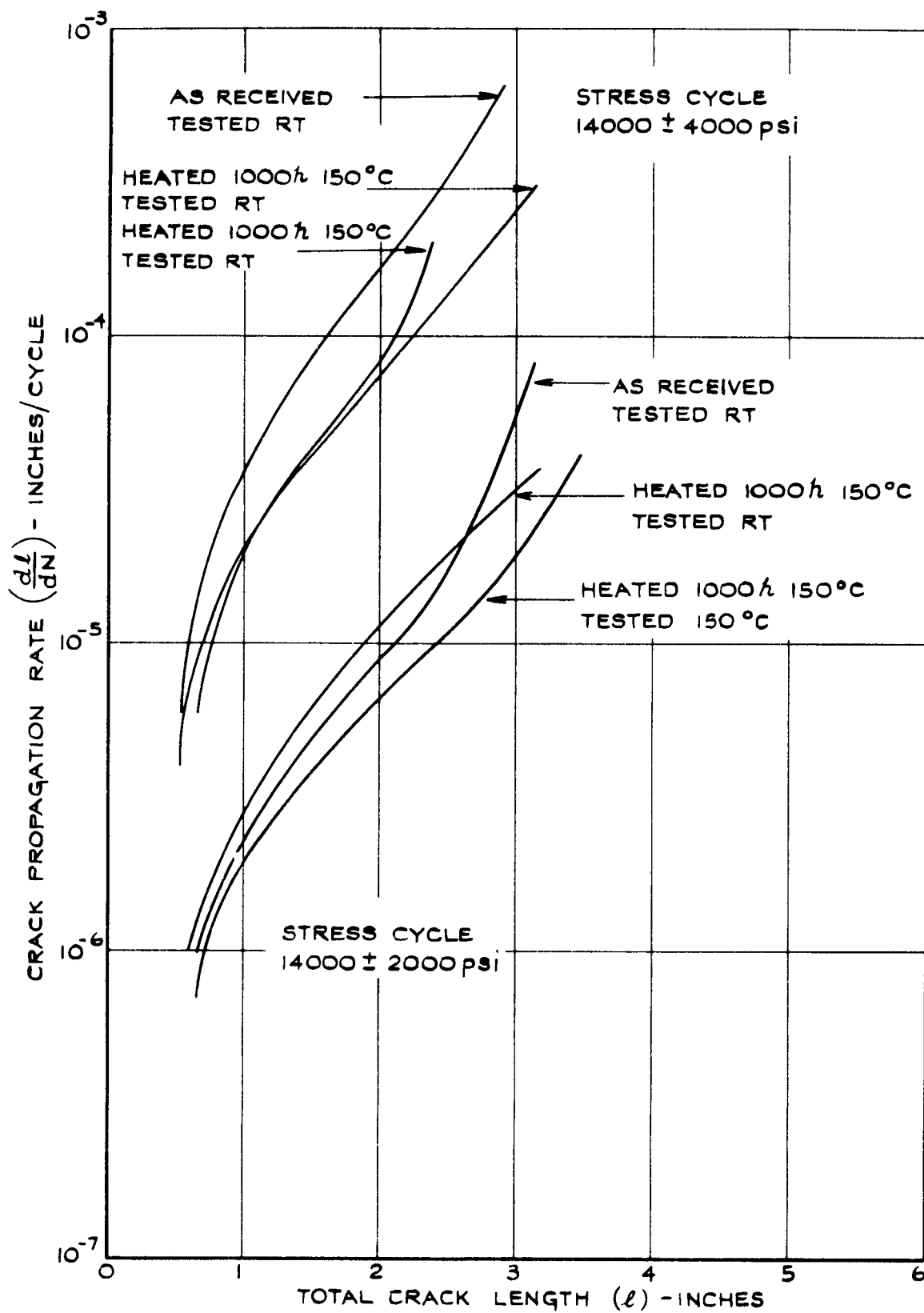
FIG.11 EFFECT OF PRIOR HEATING AT 150°C ON CRACK PROPAGATION RATES IN 2024-T81 SHEET

Fig.12   CPM/R/479
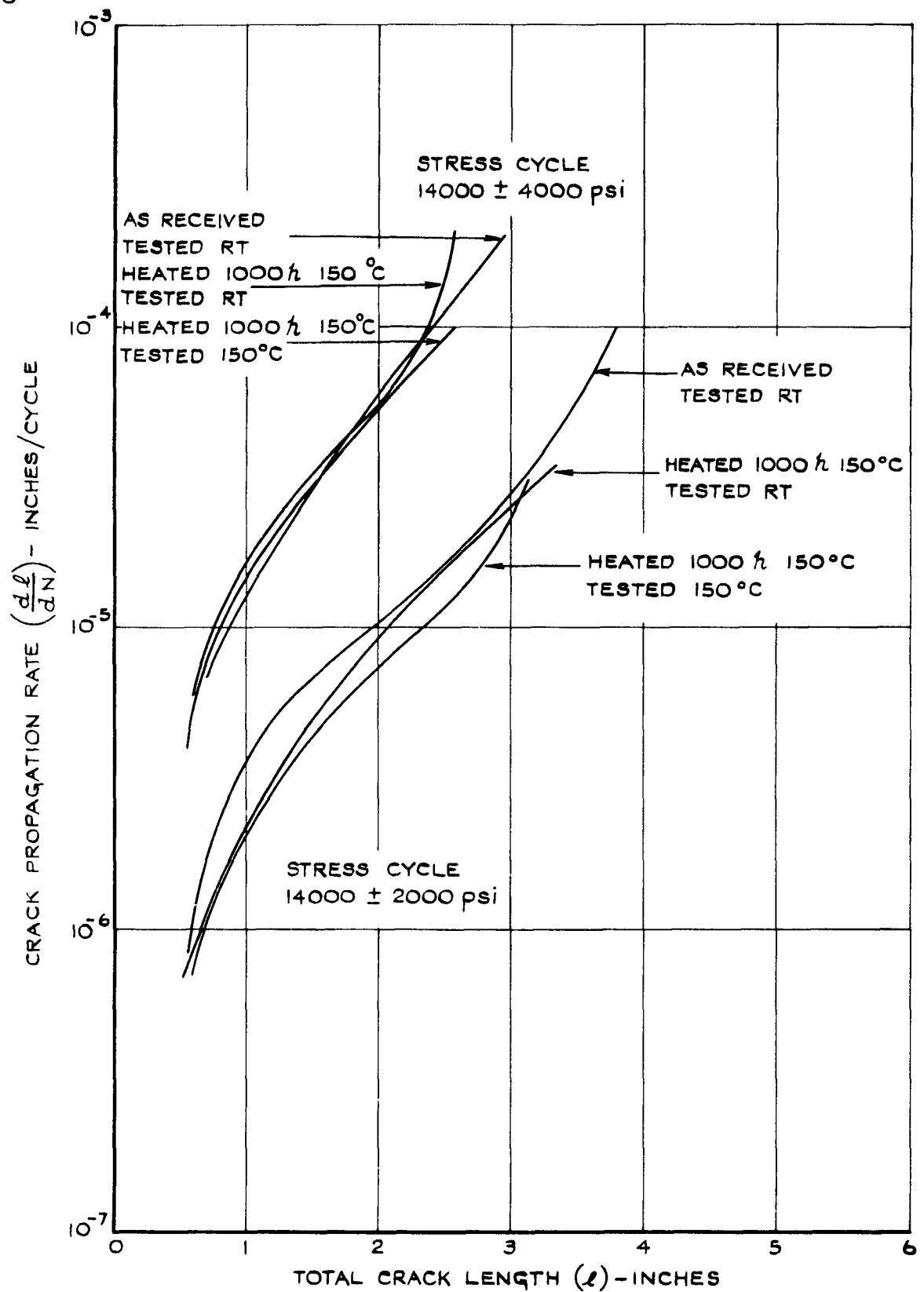
FIG.12   EFFECT OF PRIOR HEATING AT 150° C ON CRACK PROPAGATION RATES IN D.T.D 5070 SHEET
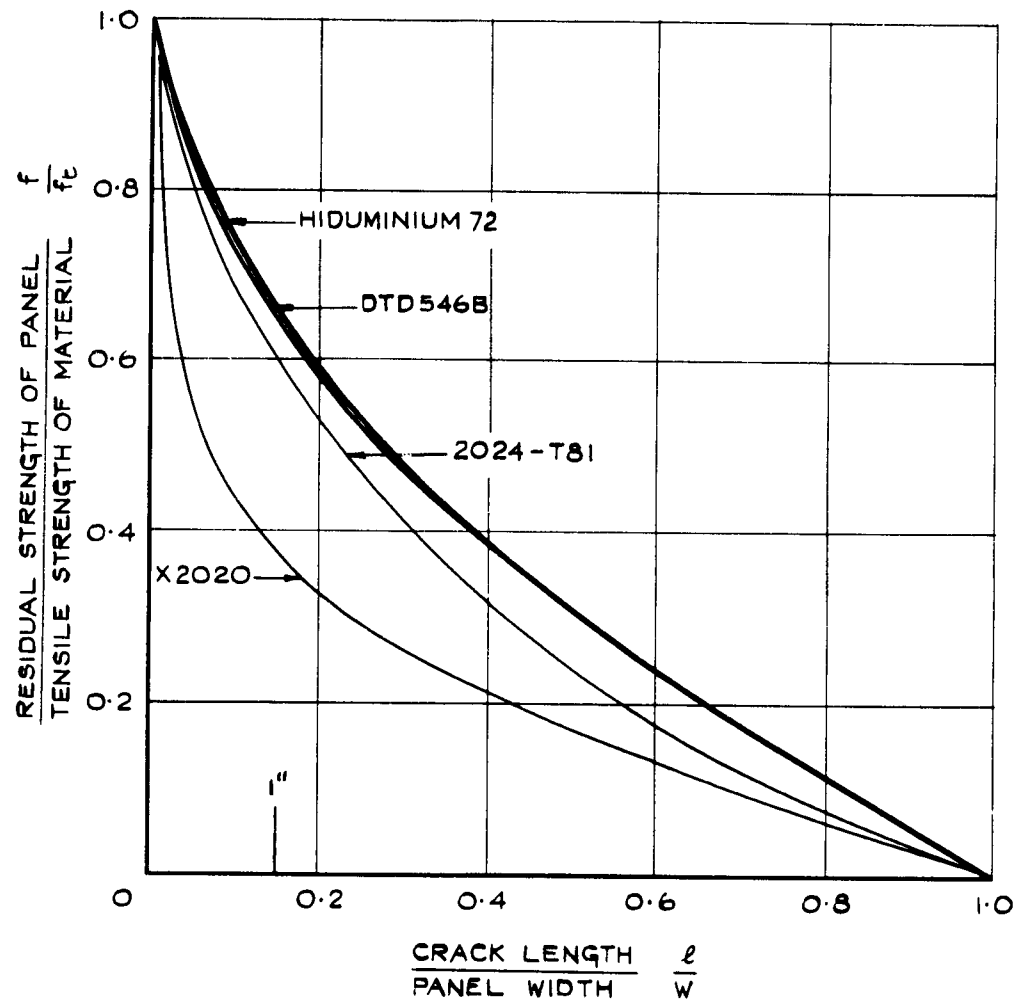
FIG.13   RESIDUAL STRENGTHS OF CRACKED PANELS

Fig.14   CPM/R/481
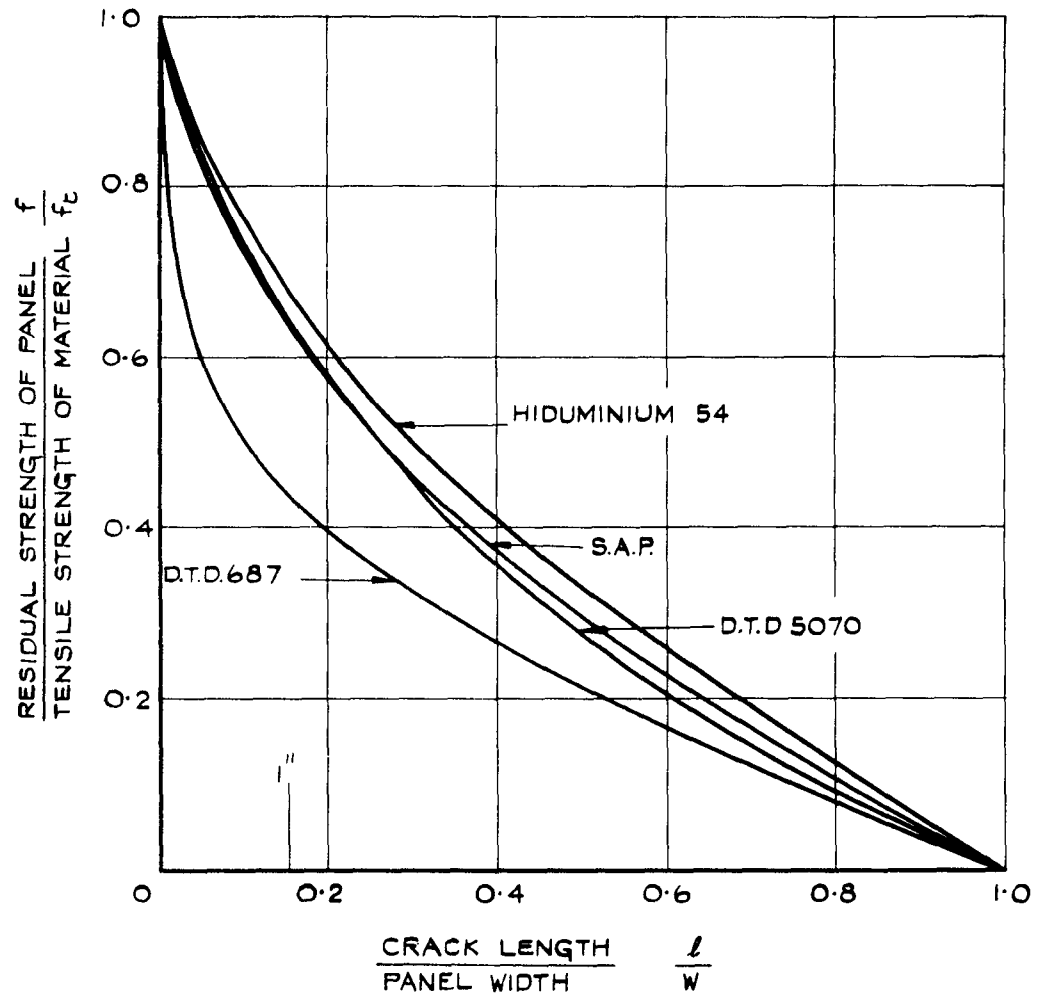
FIG. 14 RESIDUAL STRENGTHS OF CRACKED PANELS
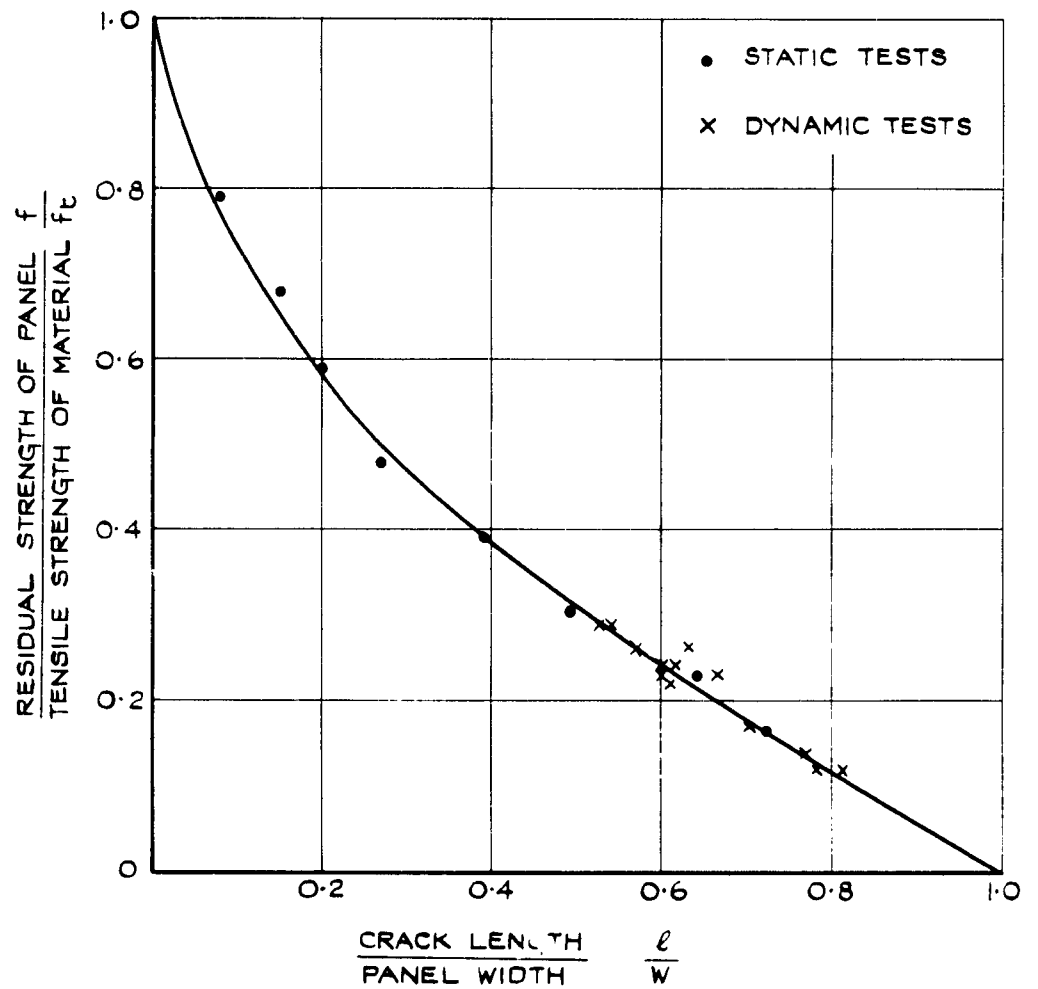
FIG. 15   RESIDUAL STRENGTHS OF D.T.D. 546B

PANELS CONTAINING CRACKS

Fig.16   CPM/R/483
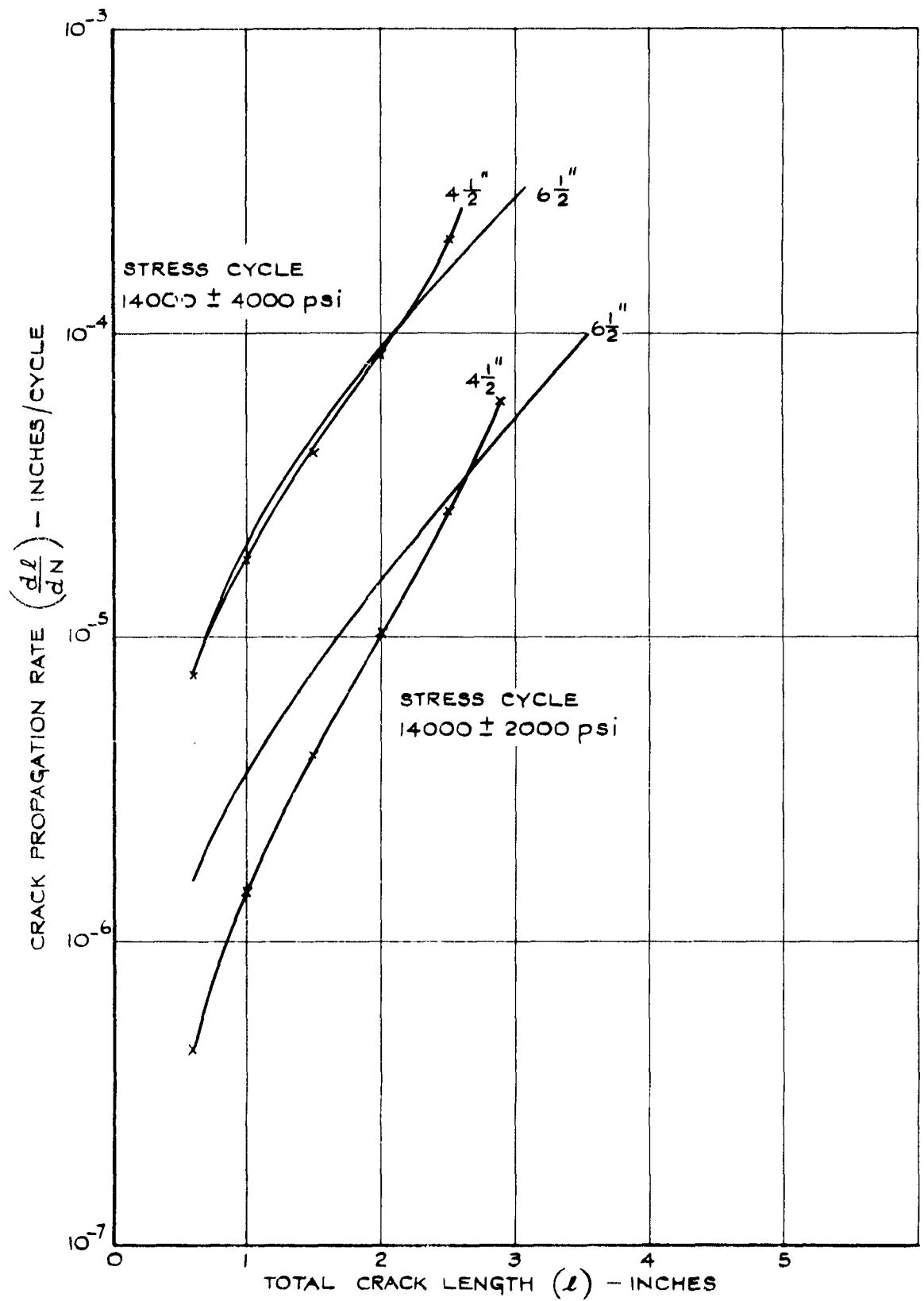
FIG.16   EFFECT OF PANEL WIDTH ON CRACK
PROPAGATION RATES IN D.T.D. 546B SHEET
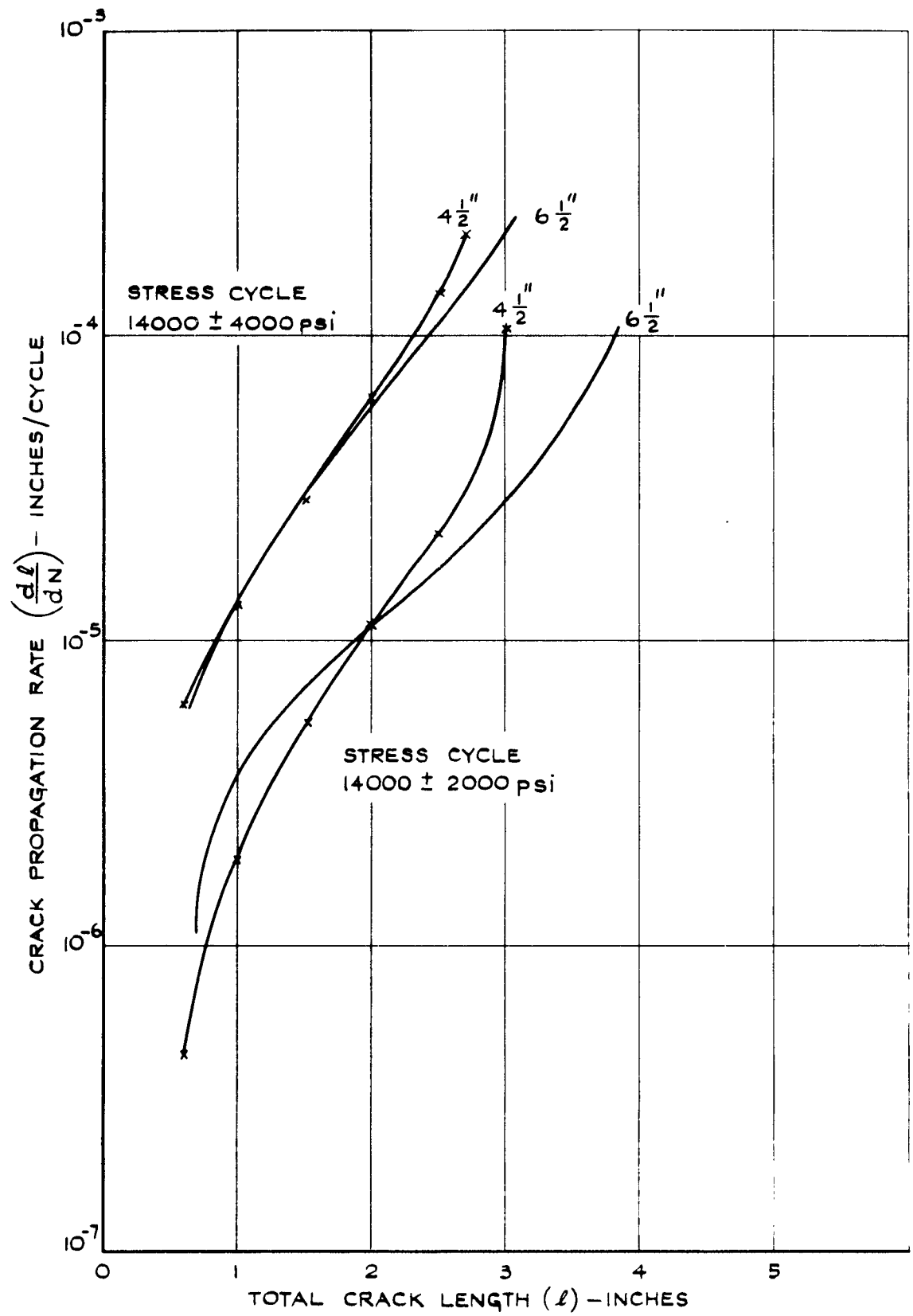
FIG. 17   EFFECT OF PANEL WIDTH ON CRACK
PROPAGATION RATES IN D.T.D. 5070 SHEET
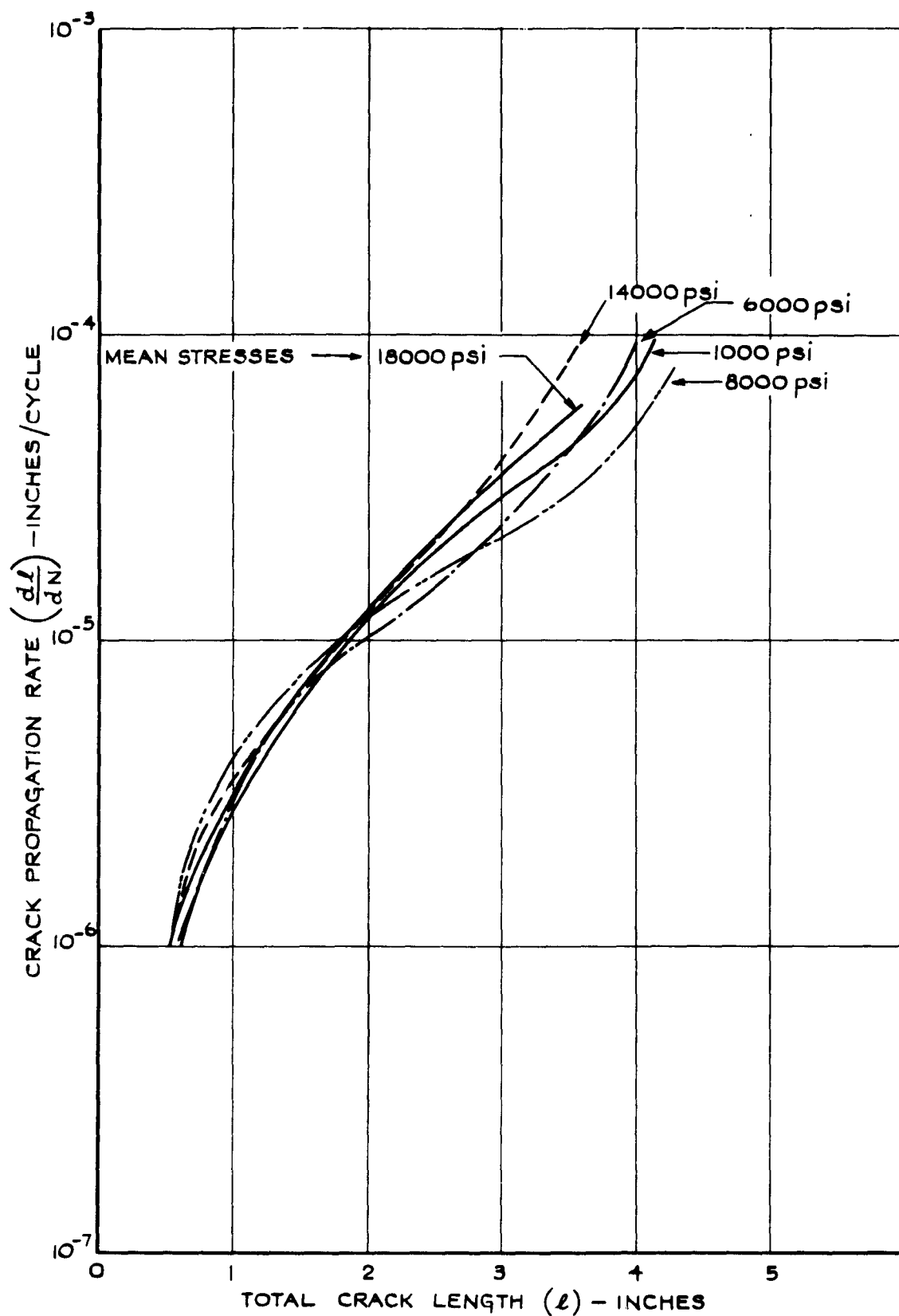
FIG.18   EFFECT OF MEAN STRESS ON CRACK PROPAGATION RATES IN D.T.D 546B SHEET (ALTERNATING STRESS ± 2000 psi IN ALL TESTS)
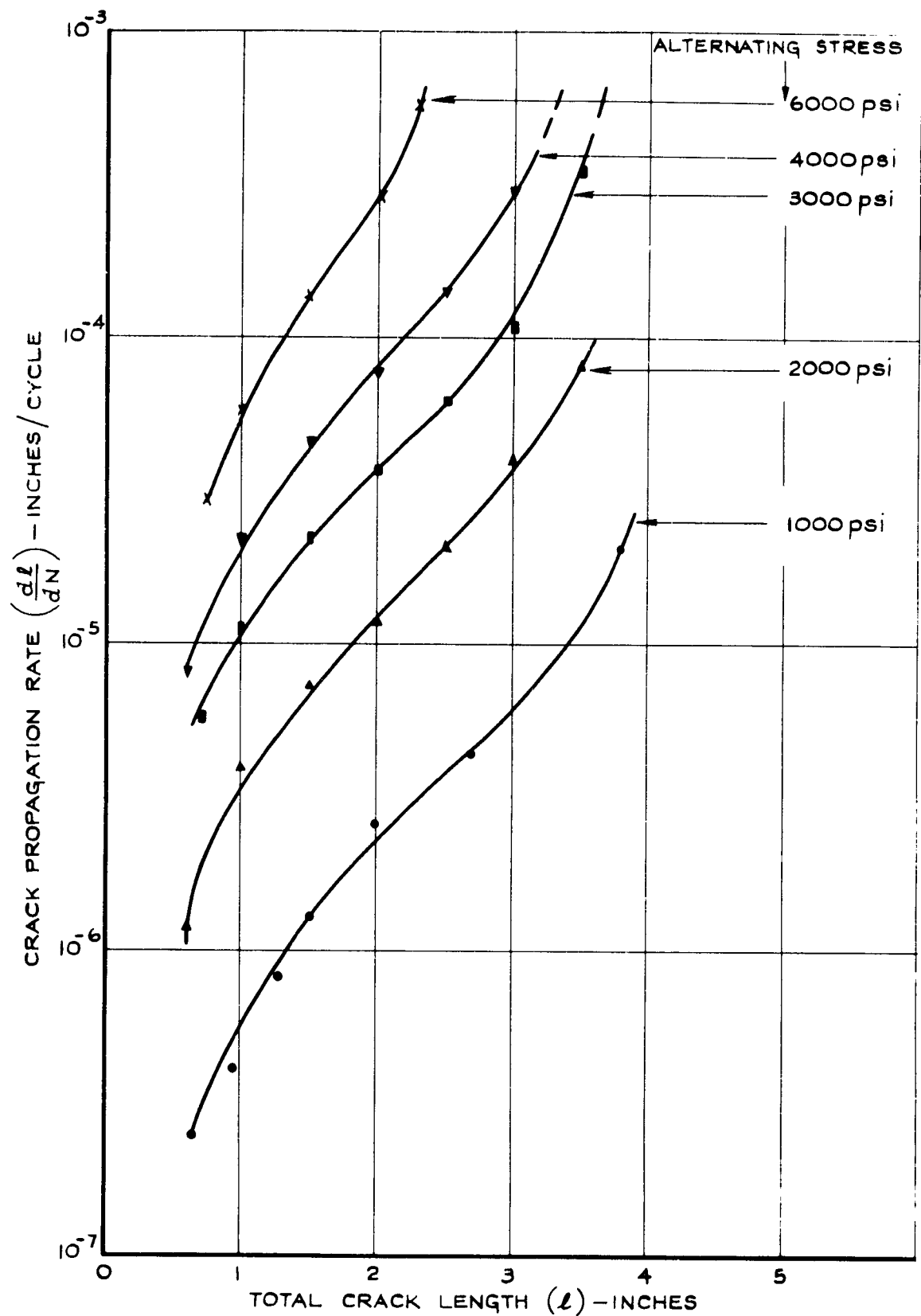
FIG.19   EFFECT OF ALTERNATING STRESS ON CRACK
         PROPAGATION RATES IN D.T.D. 546B SHEET
         (MEAN STRESS 14,000psi IN ALL TESTS)

Gunn, N. J. F.

539.219.2:
620.178.3:
669.715:
621.415

FATIGUE CRACKING RATES AND RESIDUAL STRENGTHS OF EIGHT ALUMINIUM
SHEET ALLOYS

Royal Aircraft Establishment Technical Report 64024 October 1964

Eight aluminium sheet alloys were tested as $6\frac{1}{4}"$ wide 16 SWG panels containing $\frac{1}{4}"$ central transverse slots, to compare the propagation rates of fatigue cracks which grew from the slots under $P \pm p$ type stressing. The results are given as cracking rate vs crack length curves. With the lowest stress cycle, $14,000 \pm 2000$ psi, cracking rates at $1"$ crack lengths ranged from 0.16×10^{-5} in/cycle in Hiduminium 54 to 1.1×10^{-5} in/cycle in DTD.687A, the rate in DTD.5070 sheet being 0.36×10^{-5} in/cycle. With the highest stress cycle, $18,000 \pm 4000$ psi, cracking rates at $1"$ crack lengths were about 10 to 20 times faster, and again the DTD.5070 sheet had an intermediate rate similar to those of DTD.5468 and 2024-T81. Heating 2024-T81 and DTD.5070 panels for 1000 hours at 150°C caused only small changes in cracking rates, and rates

(Over)

Gunn, N. J. F.

539.219.2:
620.178.3:
669.715:
621.415

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(Over)

measured in tests at 150°C were very similar to those at room temperature. Residual strengths at 1" crack lengths ranged from 37% for X 2020 to 67% for DTD.5468 and Hiduminium 54, with DTD.5070 retaining 64%.